Cape Fear Public Utility Authority
Stewardship. Sustainability. Service.

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November 16, 2017

The Honorable Trudy Wade
North Carolina General Assembly
Legislative Building
16 West Jones Street
Raleigh, North Carolina 27601

RE: HB56 GenX Response Measures
Cape Fear Public Utility Authority (CFPUA) Interim Report

Dear Senator Wade:

In accordance with House Bill 56 GenX Response Measures requirements, this interim report summarizes our coordination activities with Brunswick and Pender counties. We maintain an ongoing dialogue with their County Managers, as well as their Public Utility and Health departments.

CFPUA has provided both counties all our Cape Fear River raw and finished (treated) water laboratory sampling results for GenX at the Sweeney Treatment Plan. In addition, we have retained the engineering consultant firm, Black & Veatch, to conduct "Emerging Contaminates Treatment Strategy Piloting" tests of various types of filtration media for GenX and other perfluoroalkyl substances (PFAS). Granular Activated Carbon (GAC) and Ion Exchange Resin column tests have been conducted at the Sweeney Plant since July, and those results captured in three Technical Memorandum reports (enclosures 1, 2, 3) from Black & Veatch have been shared.

CFPUA is also conducting an accelerated column test at Calgon's facility in Pittsburgh. When the results of this study are available, this information will be provided. We anticipate entering into another agreement with Black & Veatch for additional assistance with interpreting test results, further pilot testing of other GAC's and resins, regulatory assistance and preparation of an engineering report. This testing and the final report will be crucial in deciding the future path to filter and treat emerging compounds which are being discovered.

CFPUA has formed a close partnership with University of North Carolina – Wilmington (UNCW) to identify PFAS compounds in the river. Professor Ralph Mead and his team in the Department of Chemistry and Biochemistry, have been conducting sampling testing standards work to identify compounds and their quantity in the river. We have met with his team several times, and they've provided two monthly summaries of their work (enclosures 4, 5). These reports are also shared with both counties as they become available.

Finally, we've had many discussions with both counties related to this issue. We maintain a united sense of purpose in our mission to provide our customers drinking water of the highest quality.

Please contact me at (910) 332-6558 if you have any questions, or by email at jim.flechtner@cfpua.org.

Sincerely,

James R. Flechtner, P.E.
Executive Director

CC: Linda Miles, CFPUA Consulting Attorney
File

Enclosures (5):
(1) Technical Memorandum 1 Desktop Evaluation of Alternatives – GenX and other PFAS Treatment Options Study
(2) Technical Memorandum 2 Preliminary Report on Prescreened Alternatives – GenX and other PFAS Treatment Options Study
(3) Progress Update - Emerging Contaminants Treatment Strategy Pilot Study
(4) UNCW Study September 2017
(5) UNCW Study for October 2017

FINAL

TECHNICAL MEMORANDUM 1

Desktop Evaluation of Alternatives – GenX and Other PFAS Treatment Options Study

B&V PROJECT NO. 196369

NORTH CAROLINA
PROFESSIONAL
SEAL
8749
ENGINEER
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7/21/17

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Prepared for

Cape Fear Public Utility Authority

JULY 2017

BLACK & VEATCH

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Executive Summary

Anthropogenic (human-made) organic chemicals known as perfluoroalkyl substances (PFASs) have been detected in water from the Cape Fear River, which supplies the Sweeney Water Treatment Plant (WTP). These compounds include GenX and several others recently identified by a study performed by Dr. Knappe. PFASs are used in a wide variety of manufactured products. Because of their widespread use, most people have been exposed to PFASs. PFASs have been found in many types of waters worldwide.

Neither the Environmental Protection Agency (EPA) nor the North Carolina Department of Environmental Quality (NC DEQ) has set enforceable maximum contaminant levels (MCLs) for GenX or other PFASs. Because of concern over potential health effects associated with these compounds in drinking water, Cape Fear Public Utility Authority (CFPUA) is proactively considering the feasibility and effectiveness of treatment alternatives. CFPUA is one of the first utilities within the United States to pursue enhanced treatment that targets removal of these compounds.

The following list summarizes the main findings of this technical memorandum, which presents a preliminary evaluation of the technical feasibility of water treatment methods:

- Conventional water treatment methods, such as coagulation, clarification, and granular media filtration, are not effective at removing PFASs, including GenX, as shown in a major research study of 15 full-scale WTPs.
- Various studies have shown that granular activated carbon (GAC) media, ion exchange (IX), and reverse osmosis or nanofiltration (RO/NF) are effective at removing PFASs, but the available results are limited, and almost no information specifically addresses GenX.
- For GAC, two options are available: 1A, installing new GAC media in the existing filters, and 1B, locating new GAC contactors, consisting of basins similar to the existing filter boxes, downstream from the existing filters. Both Option 2, installing new anionic IX exchangers, and Option 3, RO/NF, would also be located downstream of the existing filters.
- Option 1A, installing new GAC in the existing filters, would be the lowest initial cost option with the shortest implementation time, however, operating costs would be directly influenced by replacement frequency, which is currently unknown. New GAC media would cost $1 million to $2 million per replacement event.
- To provide an improved basis for decision-making, site-specific testing of these processes (GAC, IX, and RO/NF) is recommended to refine the understanding of design and operational parameters that would affect feasibility and cost.
- Since the lowest initial cost option would be Option 1A, one logical approach would be to conduct GAC media testing on water with Sweeney WTP concentrations to consider the viability of this option before a larger testing program is started.
- As a parallel path activity while testing proceeds, it is recommended that planning-level cost opinions be developed for the lowest and highest cost options, Option 1A and Option 3. The development of the cost opinions would be based on preliminary assumptions that could subsequently be revised when site-specific test results are available.

1.0 Purpose

This document presents a preliminary evaluation of the technical feasibility of several water treatment methods that have been proposed for removal of the anthropogenic (human-made) organic chemical known as GenX and other compounds recently identified. This contaminant, GenX, has only recently been identified as a concern within the field of drinking water treatment, and limited treatment information is available. This evaluation is based on engineering assumptions and extrapolations that could be confirmed by subsequent bench-scale and/or pilot-scale testing before full-scale implementation.

2.0 Introduction

2.1 GENERAL INTRODUCTION

There is a group of organic chemical compounds, collectively referred to as perfluoroalkyl substances (PFASs), also sometimes called perfluorinated compounds (PFCs). The term PFAS is used in this memorandum. Various PFASs have been used in a wide variety of manufactured products, such as firefighting foams, carpets, clothing, cosmetics, food packaging, and cookware. Because of their widespread use, most people have been exposed to PFASs. PFASs have been found in many types of waters worldwide. As shown in the recent literature review by Dickenson and Higgins (2016), this includes the United States, Germany, Canada, South Korea, China, Brazil, United Kingdom, France, Italy, and Spain. As an indication of how widespread these compounds are, a study by Houde et al. (2006) observed the presence of PFASs in the blood of animals in remote areas in the arctic.

Lists of compounds that make up PFASs, as well as information on molecular weight and chemical formula, can be found in various references (including Dickenson and Higgins 2016; Sun et al. 2016; and Water Research Foundation 2016). One specific type of PFAS of special interest to CFPUA, which is known by the trade name GenX, was detected by Sun et al. (2016) in the Cape Fear River at an average concentration of 631 nanogram per liter (ng/L).

GenX is used as a processing aid for the production of fluoropolymer materials. It is the ammonium salt of perfluoro-2-propoxypropanoic acid (PFPrOPrA), according to Heydebreck et al. (2015). PFPrOPrA has the chemical formula $C_6HF_{11}O_3$, a molecular weight of 330 Dalton, and Chemical Abstracts Service (CAS) Registry No. 13252-13-6. According to *The News Journal*, June 27, 2017 (Mordock 2017), Chemours, a company that had been discharging wastewater containing GenX from its Fayetteville, North Carolina, facility to the Cape Fear River about 100 miles upstream from Wilmington, North Carolina, announced that it had temporarily stopped discharging wastewater containing GenX while determining how to address the issue. On June 27, 2017, the North Carolina Department of Environmental Quality (NC DEQ) confirmed that Chemours had stopped discharging GenX wastewater to the Cape Fear River (https://deq.nc.gov/deq-verifies-chemours-has-stopped-discharging-genx-wastewater). Even if the GenX discharge is not restarted, it is anticipated that concentrations of a stable chemical such as GenX may remain in the river for a period of time. It appears that Chemours may be continuing to discharge wastewaters containing other PFAS compounds; information to revise that possibility has not been found.

2.2 REGULATORY HISTORY

Allowable concentrations of PFASs in drinking water is a relatively new topic being considered by the United States Environmental Protection Agency (EPA). The EPA has not issued any regulations regarding PFASs in drinking water, and there are therefore no enforceable maximum contaminant levels (MCLs) for PFASs. However, in 2009, on the basis of the limited health effects information available at that time, the EPA published provisional health advisories for two PFAS compounds: perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS). For reference, the formula for PFOA is $C_7F_{15}COOH$, and it has a molecular weight of 414 Daltons, and PFOS is $C_8F_{17}SO_3H$, and it has a molecular weight of 500 Daltons. In May 2016, the EPA issued revised health advisories for PFOA and PFOS of 70 ng/L, measured either individually or in combination (EPA 2016). The EPA develops health advisories to provide information on contaminants that it believes may cause human health effects and are known or anticipated to occur in drinking water. These health advisories are "non-enforceable and non-regulatory and provide technical information to states agencies and other public health officials" (EPA 2016). There are currently no EPA regulations or health advisories regarding GenX. Although there are no enforceable MCLs for GenX or other PFASs, the Cape Fear Public Utility Authority (CFPUA) is proactively considering the feasibility and effectiveness of treatment alternatives because of concern over potential adverse health effects associated with the presence of these compounds in drinking water.

2.3 TREATMENT METHODS

A major goal of Water Research Foundation Project 4322 (Dickenson and Higgins 2016) was to evaluate removal of PFASs at 15 full-scale water treatment systems throughout the United States, including two potable reuse treatment systems. This study found that conventional water treatment methods, including aeration, chlorination, chloramination, chlorine dioxide, coagulation, flocculation, anthracite media filtration, microfiltration or ultrafiltration, ozonation, permanganate addition, sedimentation, softening (caustic softening followed by solids contact clarification), and ultraviolet (UV) light, were not effective at removing PFASs. In addition, the literature review showed that other researchers have confirmed that these treatment processes provide essentially no removal of PFASs.

Dickenson and Higgins (2016) conducted bench-scale testing of granular activated carbon (GAC) and nanofiltration (NF), as well as observation of a certain type of ion exchange (IX) resin and full-scale reverse osmosis (RO), noting that each of these methods provided varying levels of removal of PFASs. Therefore, these treatment methods (GAC, IX, and RO/NF) are considered in this memorandum.

2.4 TREATMENT AT THE SWEENEY WTP

The existing Sweeney Water Treatment Plant (WTP), which has a rated capacity of 35 million gallons per day (mgd), applies the following processes: ozonation (pre and intermediate), coagulation, flocculation, clarification, biological filtration using GAC media, disinfection including UV, and chlorination. The granular media filtration consists of (from bottom to top) underdrains and gravel, sand, and GAC. The sand layer is 12 inches deep with an effective size of 0.4 to 0.5 millimeters (mm) and a uniformity coefficient of 1.4. The GAC layer is 48 inches deep. The four older filters (1 through 4) initially used Calgon Filtrasorb 300 (coal-based carbon). The GAC in filters 3 and 4 has been in service since 1997; in 2005 the media was replaced in filters 1 and 2 during maintenance work on the underdrains. The other filters use a similar type of coal-based carbon called VGAC 8x30 SNC that has been in service since 2010 (filters 5 to 9) and 2011 (filters 10 to 15). There are 14 filters, as summarized in Table 2-1. On the basis of current demands, typical operating conditions are 25 mgd on higher flow days and 12 mgd on lower flow days (which equate to loading rates of 2.8 gallons per minute per square foot (gpm/ft^2) and 1.4 gpm/ft^2, respectively). These figures indicate a typical loading rate of 2.5 gpm/ft^2 and an empty bed contact time (EBCT) of approximately 12 minutes in the GAC portion of the filter. Water quality of the combined filter effluent is listed in Table 2-2.

Table 2-1 Description of Existing Filters

PARAMETER	UNIT	VALUE
Number of Filters	Number	14
Cells per Filter	Number	1
Area per Filter	ft^2	435
Dimensions, L x W x D	ft	15 x 29 x 15.58
Hydraulic Loading	gpm/ft^2	4
Capacity Rating, each filter	mgd	2.5

Table 2-2 Water Quality of Combined Filter Effluent (2016-2017)

PARAMETER	UNIT	TYPICAL	MINIMUM	MAXIMUM
Temperature	°C	20.9	10.0	31.0
pH	Standard unit	5.7	4.8	6.4
Turbidity	NTU	0.032	0.01	0.68
Alkalinity	mg/L as $CaCO_3$	8	5	14
TOC	mg/L	2.1	1.7	3.1
UV 254	1/cm	0.019	0.008	0.036
Conductivity	µS/cm	176	162	193
NTU = nephelometric turbidity unit cm = centimeter µS/cm = micro-Siemens per centimeter				

3.0 Analytical Measurement of PFAS and GenX

It has been determined that here are two commercial analytical laboratories that offer measurement of PFASs, Eurofins and Test America, based on discussions with researchers in the field, however, only Eurofins is currently providing GenX measurements. Information provided by these laboratories on reporting limits, costs, and sample turn-around time is presented in Table 3-1. Regarding PFASs other than GenX, Eurofins provides measurement for 14 compounds and Test America 17. There are also some non-commercial laboratories that measure PFAS concentrations, including Dr. Knappe's laboratory at North Carolina State University (NCSU), EPA, Colorado School of Mines, and the State of Minnesota. Dr. Knappe has said (personal communication) that NCSU and EPA Region 4 can measure GenX as well as other similar perfluorinated ethers.

Table 3-1 Survey of Analytical Laboratories

PARAMETER	EUROFINS	TEST AMERICA
Provides GenX Measurement?	Yes	No
GenX Method	SPE extraction/preconcentration LC Liquid Chromatography, MS Mass Spect	NA
GenX Reporting Limit, ng/L	10	NA
Price per Sample	$350	NA
Turn-around Time, at cited price	10 Business Days	NA
Sample Holding Time	14 Calendar Days or possibly longer since GenX is quite stable	NA
Provides Measurement of Other PFAS?	Yes	Yes
Number of PFASs in Lab's Standard Package	14	17
Other PFAS Method	Method 537	Method 537
Other PFAS Reporting Limit, ng/L	2.0	2.0
Price per Sample	$325	$250 to $300
Turn-around Time, at cited price	10 Business Days	10 Business Days
Sample Holding Time	14 Calendar Days	14 Calendar Days

4.0 Granular Activated Carbon Treatment Option

4.1 INTRODUCTION

Granular activated carbon (GAC) adsorption is a water treatment process that uses a granular media produced from carbon-based materials such as coal, coconut shells, peat, or wood that have been "activated" by heat and sometimes other manufacturing steps to yield the desired properties. There are many types of GAC media, and selection of an effective carbon for a given situation is frequently based on site-specific testing. Water treatment applications include use as a granular media for filtration to remove particulates and turbidity as well as to remove certain dissolved materials, such as organic constituents that can result in color or the formation of disinfection byproducts (DBPs), taste and odor (T&O) causing compounds, or industrial solvents if present in the water. GAC is also sometimes used to dechlorinate water.

GAC is implemented in water treatment in one of two roles: one, as a filter-adsorber, providing both filtration and adsorption functions or, two, as a post-filter contactor in which adsorption is the primary treatment objective. As the adsorptive capacity of the GAC becomes exhausted, microbial growth on the GAC can be used to convert some of the chemicals in the water to cell mass. This is referred to as biofiltration. The GAC filters at the Sweeney plant operate as biofilters.

When applied as a biologically active filter, microbial activity on the GAC causes the removal of some organics. Adsorption of organic materials on the carbon can also occur. Both of these mechanisms can occur simultaneously when the GAC media is new or recently regenerated. In a typical scenario with new GAC media almost all of the organic material that is chemically attracted to the GAC would be removed. As the adsorption "sites" on the GAC are filled, the adsorptive ability of the carbon becomes exhausted, resulting in a "breakthrough" in which the concentration of organic chemicals being removed increases in the effluent from the GAC filter.

Total Organic Carbon (TOC) is a complex mixture of many organic compounds. Some are adsorbed better by GAC than others, and there is often a small fraction, 5 to 10 percent, that is not adsorbed at all. The nonadsorbable fraction passes to the effluent. Some TOC is removed by biodegradation in the GAC bed after the bed's adsorption capacity has been exhausted. Consequently, a typical TOC breakthrough curve comprises three stages:

1. Immediate breakthrough of the nonadsorbable component of TOC (typically 5 to 10 percent of influent TOC).
2. Removal of TOC by adsorption (decreases with time as the adsorption capacity of the GAC is consumed) and varies by chemical.
3. Continued biological removal of a portion of the TOC.

Each type of GAC exhibits a selectivity or preference for some organic species over others. In addition, when breakthrough occurs, a phenomenon called "chromatographic peaking" may take place. When this happens, the GAC releases some types of organic material that were adsorbed previously while removing other types instead (in a sense trading one that it "prefers" for the other). From a practical standpoint, the outcome of that event is that there can be higher concentrations of some organic chemicals in the effluent than in the influent. A simplified diagram to help explain chromatographic peaking is presented on Figure 3-1. The drawing on the left side of the figure shows new GAC media (or new IX resin which also exhibits chromatographic peaking) that is removing all of the "A" and "B" molecules that are present in the influent water. The drawing on the right shows exhausted GAC media (or IX resin), treating the same influent concentrations of

"A" and "B" while the sites attracted to "A" and "B" are full. On the right side the exhausted media/resin is releasing "A" molecules that have already been captured because there is a preference to attract "B" molecules. On the right side the concentration of "A" in the effluent is greater than in the influent because "A" molecules are being released.

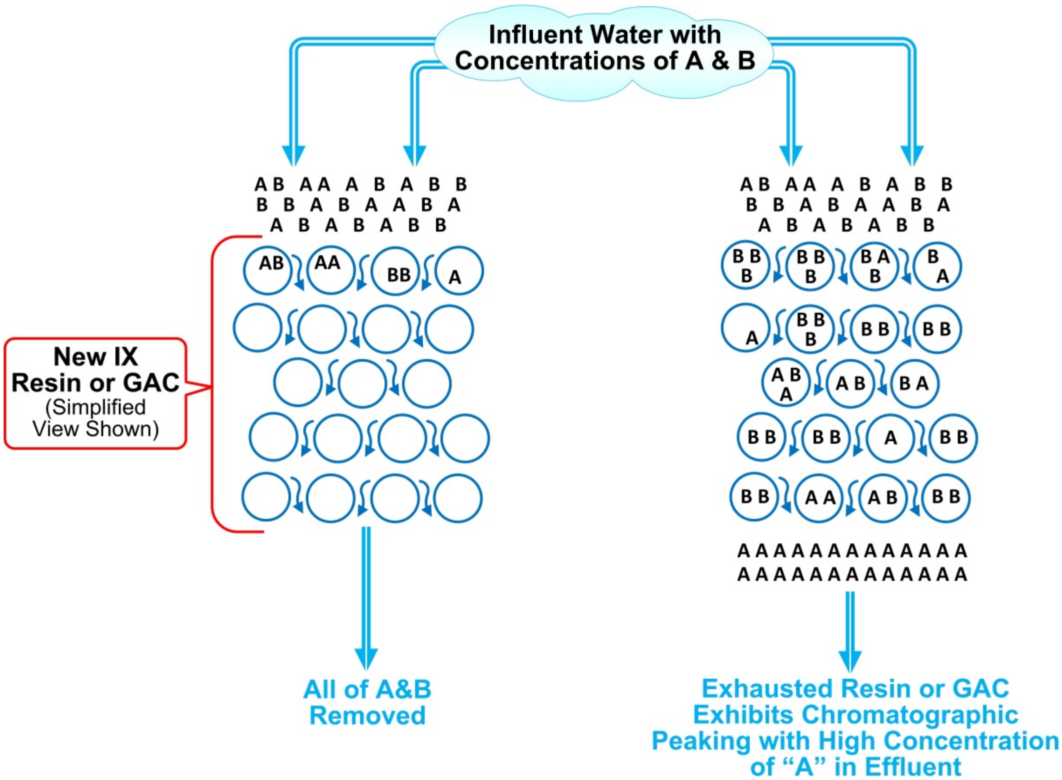

Figure 3-1 Diagram of Chromatographic Peaking

Because of the biological removal mechanism, even after the adsorptive capacity of the GAC is exhausted, a portion of the TOC concentration in the water is removed, essentially consumed, by microbes. In many surface water supplies, typically about 10 to 20 percent of the TOC is biodegradable and removed in this way. When the adsorption ability of a GAC bed is exhausted the media needs to be regenerated or replaced to continue to remove organics by adsorption. Preliminary discussions with GAC providers, in regard to the GenX application being considered in this document, indicate that the spent GAC would be shipped off-site for regeneration and replaced with new or regenerated carbon.

Key parameters that affect the design, operation, and costs of applying GAC include loading rate (LR), EBCT, and number of bed volumes (BVs) to breakthrough.

LR is the flow rate per cross-sectional area and, in the United States, that value is typically presented in gpm/ft^2. Even with clean filters, as LR increases, the pressure drop across the filter also increases. When applied to filter/adsorbers, LR is an additionally important variable. In that service, the filter media removes particles from the water. As the filter gets fouled (or plugged) with accumulated particles, the filters are periodically backwashed by the plant staff to remove the captured particles and maintain the pressure drop within a desired range.

EBCT is the amount of time, typically measured in minutes, that the water is in contact with the media with the assumption of an empty bed to facilitate comparison of different media on a common basis. Sufficient EBCT is needed to allow enough time for the chemicals being removed to transfer to the GAC. If EBCT is too short, removal will be inadequate. After LR and EBCT are established, bed height can easily be calculated.

BV is the number of volumes of water that can flow through the GAC before breakthrough occurs. In comparing two different types of GAC, the product that treats the higher number of BVs before breakthrough of the target compound would require less frequent replacement or regeneration. If the number of BVs treated is low, and hence the replacement frequency is high, other treatment methods may be more cost-effective. Each new set of GAC installed in the existing filters would cost $1 million to $2 million, according to discussions with carbon suppliers.

4.2 APPLICATION TO PFAS

Experience with removing PFASs with GAC is summarized in this section.

A key study that included application of GAC to remove PFASs was conducted by Dickenson and Higgins (2016). Their literature review concluded that few studies have been published on the effectiveness of PFAS removal methods, citing Quinones and Snyder (2009); Post et al. (2009); Takagi et al. (2008); Eschauzier et al. (2012). Some batch test studies on PFAS removal by GAC have been published by Deng et al. (2010); Yu et al. (2009); Senevirathan et al. (2010); Lampert et al. (2007) on removal of PFOS and PFOA as well as by Carter et al. (2010) on removal of perfluorobutane sulfonate (PFBS). These studies showed the effectiveness of GAC at removing certain types of PFAS compounds but did not include GenX.

Dickenson and Higgins (2016) evaluated GAC performance for removing PFAS at four full-scale facilities (Utilities 7, 8, 18, and 20). The PFAS concentrations at Utility 8 were too low, so that part of the study was discontinued. Utility 20 applied Calgon F600 (coal-based carbon) in a lead-lag arrangement with about 13 minutes of EBCT in each contactor, which equates to about 10,000 BV every 3 months. The authors reported that Utility 20 operated its lead contactors for approximately 10 months before initial breakthrough of evaluated PFAS. With effluent from the lead contactor feeding the lag contactor, concentrations in the lag effluent for all except one type of PFAS in the study were maintained below detection limits for the 1 year period studied. Utility 18 applied Calgon F300 (coal-based carbon) for surface water treatment. The carbon had already been in service for more than 6 years at the time of the study, and it was observed that effluent concentrations for some PFASs were higher than influent concentrations, so it is possible that leaching and/or chromatographic peaking occurred. Another study (Takagi 2011) was cited as observing a similar case where fresh carbon was initially effective at PFAS removal but was not effective 1 year later. Utility 7 applied Norit GAC300 (coal-based carbon) with EBCT of about 10 minutes and observed removal of many types of PFASs to below detection limits, while three shorter chain PFASs (which were described as perfluorobutanoic acid [PFBA], perfluoropentanoic acid [PFPeA], and perfluorohexanoic acid [PFHxA]) exhibited partial removal at 33 percent, 74 percent, and 91 percent, respectively.

Dickenson and Higgins (2016) conducted a type of bench-scale testing known as rapid small-scale column tests (RSSCTs) on three types of GAC: Calgon F300 (coal-based with Iodine No. 900 I2/g), Calgon F600 (Iodine No. 850 I2/g), and Siemens (now Evoqua) 1240C (coconut-based). RSSCT results for F300 while treating spiked deionized water, exhibited initial breakthrough of some PFASs at about 30,000 BV, while other effluent concentrations did not exceed 2 percent of the influent values after 98,000 to 125,000 BV. There was some indication that smaller chain PFASs had earlier breakthroughs, and a "general chain length dependent pattern was observed, but it did not hold true for all of the PFCAs (PFAS compounds studied)"; therefore, it is difficult to extrapolate the anticipated level of GenX removal at this time. Additional RSSCT results from tests of GAC treating a spiked creek water with a background dissolved organic carbon concentration of 1.7 mg/L yielded lower numbers of BVs to breakthrough. When applied to the creek water, all three GACs had a breakthrough of greater than 20 percent for all PFASs studied within about 11,000 BV, indicating that the presence of the background natural organic matter (NOM) competed for sites on the carbon and shortened the number of BVs. Higher concentrations in the effluent than in the influent were also observed for some of the compounds. In general, F300 provided more BVs, with about 26,000 BVs for PFOA compared to 11,000 BVs for F600 and 1240C.

Dr. Higgins, a professor at the Colorado School of Mines, and a colleague, C. Bellona, are conducting ongoing related work on removal of PFASs by GAC (personal communication). Comparing F400 and F600 from Calgon, N400 from Cabot/Norit, and a coconut-based GAC from Cabot/Norit (GCN 1240) at an LR of 2.5 gpm/ft^2 and an EBCT of approximately 11 minutes, F400 and N400 had the best performance over a 5 month pilot period. Additional testing of F400 and N400 is being planned. In their trials, F400 and N400 have so far provided in excess of 17,000 BVs without breakthrough of the PFASs of interest while treating a groundwater that included about 1.5 mg/L of background TOC. While it would be difficult to directly extrapolate the number of BVs for a surface water case such as Sweeney's, these results indicate that these types of GAC show promise in this application.

Redding (2017) showed about 30,000 and 60,000 BVs to breakthrough for PFOA and PFOS, when treating a groundwater at about 10 minutes of EBCT with influent concentrations of 67 and 49 ng/L, respectively, and 0.3 mg/L of background TOC; better performance (about 40 percent more BVs) was observed with an enhanced coconut-based carbon (1230 CX) than with a coal-based carbon (12 x 40 reagglomerated bituminous).

While none of these studies specifically focused on GenX, they show that GAC is effective at removing PFAS compounds. Studies could be conducted to quantify BV to breakthrough for the more promising GACs, including the effects of having other organics present to compete for adsorption sites, and possibly result in chromatographic peaking, at Sweeney plant conditions.

The literature review of Sun et al. (2016) discusses other studies that have shown that powdered activated carbon (PAC), a more finely powdered version of GAC, is effective at removing various PFASs, but the effectiveness decreases with chain length. However, Sun et al. (2016) indicate, "It is unclear, however, how the presence of ether group(s) [such as occurs in GenX] impacts adsorbability." The comparative testing indicated a lower removal percentage for GenX than for PFOA. For reference, GenX has a molecular weight of 330 Daltons, comprising $C_6HF_{11}O_3$, including one ether group and five perfluorinated carbons. PFOA has a molecular weight of 414 Daltons, comprising $C_8HF_{15}O_2$, including no ether groups and seven perfluorinated carbons. In the authors' view, this is the only published paper to consider removal of GenX or similar PFASs that includes an ether-based backbone by water treatment processes. The authors conclude that carbon provides some removal of GenX and similar PFASs, but that these compounds are difficult to remove. The paper suggests a need for "broader discharge control and contaminant monitoring."

4.3 ADVANTAGES

Advantages of the GAC option are as follows:

1. Essentially no capital costs or additional land (space) would be required if the option proves to be sufficiently effective when installed in existing filter boxes. Pilot-scale testing is being considered to verify that hypothesis.
2. The Sweeney WTP staff is experienced with and understands operation of the GAC filters.
3. This option has the shortest implementation time since new facilities would not be needed.
4. This option has the lowest requirements for additional labor or maintenance.
5. The option would be less energy intensive than RO/NF and would require roughly the same energy usage as for IX.
6. The option does not generate a liquid waste stream on-site. (RO/NF has that as a limitation. GAC and IX do not.)
7. The effectiveness of different types of GAC can be compared on site-specific feedwater in accelerated bench testing, which is being considered. (Accelerated testing is not practical for IX or RO/NF except for measuring RO/NF rejection.)
8. For GAC, there would be no need to increase the capacity rating (i.e., loading rate) of the existing filters or add more filters. (RO/NF has that as a limitation.)
9. All of these options have the advantage of having been applied in a wide range of WTPs, albeit for different applications than GenX removal.

4.4 LIMITATIONS

Limitations of the GAC option are as follows:

1. Performance characteristics on removing GenX and other PFASs at site-specific conditions are unknown. Testing/piloting is advised. (All of the options have this limitation.)
2. The media would require periodic replacement when exhausted. Testing/piloting is being considered to quantify the frequency of media replacement, which could be multiple times a year. (The GAC and IX options have this limitation. RO/NF membrane elements are generally replaced about every 7 years.)
3. This option is potentially susceptible to chromatographic peaking. Testing/piloting is advised to refine understanding. (The GAC and IX options have this limitation.)
4. Selectivity could limit removal of other PFASs even if the option is effective on GenX. (The GAC and IX options have this limitation. RO/NF could also exhibit selectivity but is anticipated to be less selective than GAC or IX [subject to confirmation]).

5.0 Ion Exchange Treatment Option

5.1 INTRODUCTION

Ion exchange (IX) is a water treatment process that applies the use of spherical polymeric particles that are sometimes called ion exchange resin or, less formally, "beads." IX resins are manufactured for a variety of applications. One of the most widely known examples of IX is in home water softeners. In that application, as water flows through a softener tank containing IX beads, calcium and magnesium ions, which are the source of hardness in the water, are attracted to the resin and exchanged for sodium ions. The resulting effluent has a lower hardness and an increased concentration of sodium. When most of the exchange sites are filled with calcium and magnesium, the water softening resin becomes less effective at removing them, the concentration in the effluent for those ions increases and, similar to the GAC process previously discussed, breakthrough occurs.

In a home water softener, a salt solution, generally a sodium chloride solution, is applied to regenerate the resin by converting the calcium and magnesium-filled sites back to sodium-filled sites, and after regeneration, it is placed back into softening mode. Because the calcium and sodium ions that are exchanged in this process are positively charged ions, which are also called cations, this type of IX is sometimes called cationic IX. There are other types that remove certain negatively charged species, which are called anions, so that type of IX is sometimes called anionic IX (sometimes abbreviated AIX).

Various types of IX are used in water treatment. Some full-scale WTPs use the same type of resin as home water softeners to soften water on a larger scale. Some WTPs employ other types of IX such as for nitrate or arsenic removal. Resin manufacturers offer types of anionic IX to remove certain organic materials, such as PFASs.

It should be noted that the type of resin used in a home water softener is not expected to remove GenX. The types of resins used in softeners are very different from the AIX resins that have been developed to remove PFASs. A basic chemical difference between them is that IX softeners remove certain cations from water, while the resins for PFAS treatment remove certain anions. Another difference between the IX resins used for water softening and the types developed for PFAS removal is regeneration. While softening resin is generally regenerated on-site, for PFASs removal, the resin would be returned to the manufacturer for disposal, probably by thermal destruction according to discussions with the manufacturers.

There are similarities between GAC and IX. Both processes apply media in vessels or tanks to remove certain dissolved materials from water. As previously discussed, GAC is sometimes also used to filter particulates and turbidity from water, but IX is essentially only applied to removing dissolved material. Another difference is that one of the removal mechanisms for GAC is to function as a biologically active filter that removes a portion of the TOC biologically, but IX is not applied with that mechanism. Another similarity is that, for both processes, the adsorption or exchange sites are periodically filled, resulting in breakthrough and requiring replacement or regeneration. In addition, as with GAC, IX does not remove all dissolved material equally, and the phenomenon of chromatographic peaking can result in higher effluent than influent concentrations as breakthrough occurs. For some extensively studied applications such as water softening, an IX system can be designed according to water analysis data without site-specific testing, but less is known about PFAS applications, so testing may be advised.

Another way that IX is similar to GAC is that the major parameters that impact the design, operations, and costs are the same: LR, EBCT, and number of BVs to breakthrough. The values would be different, but the concepts would be similar. A reason to consider IX as an option to GAC in this study is that a preliminary survey of the options indicates that there are IX resins that may remove PFASs to low concentrations with a higher LR and lower EBCT than GAC, which could make the process more compact and possibly more cost-effective.

5.2 APPLICATION TO PFAS

While anionic IX shows promise for removal of PFASs, the available information is quite limited. In their literature review Dickenson and Higgins (2016) summarize five studies that indicate successful removal with various resins in fairly limited testing. It would be difficult and theoretical to extrapolate from these studies to the Cape Fear River water quality. Two manufacturers of IX systems (Calgon and Evoqua applying Dow PSR2 resin) have indicated that, in their experience, the resins remove PFASs with less EBCT than GAC (for example about 2 minutes versus about 10 minutes). If a cost comparison were made between a new GAC system located downstream from the existing filtration versus a new IX system located downstream from the existing filtration, the shorter EBCT for IX would significantly reduce the size and the land area used; in that case, IX would likely result in lower cost. However, it is less clear that the costs for IX would be lower than GAC if it can be shown that installing new GAC media into the existing filter boxes would address the treatment goals. Therefore, it may be advisable to conduct some initial testing of at least one IX resin selected from the more promising types to develop operating parameters (EBCT, BV, etc.) for a comparison of IX and GAC. Unlike for GAC, there is no accepted rapid or accelerated test method for IX. Testing/piloting would be conducted in real time.

5.3 ADVANTAGES

Advantages of the IX option are as follows:

1. IX probably has a higher LR and shorter EBCT than GAC (subject to confirmation). If so, IX may be less costly than GAC if both options were to be located downstream from existing filters.
2. The option is less energy intensive than RO/NF and roughly the same energy usage as GAC.
3. The option does not generate a liquid waste stream on-site. (RO/NF has that as a limitation. GAC and IX do not.)
4. For IX, there would be no need to increase the capacity rating (i.e., loading rate) of the existing filters or add more filters. (RO/NF has that as a limitation.)
5. All of these options have the advantage of having been applied in a wide range of WTPs, albeit for different applications than this.

5.4 LIMITATIONS

Limitations of the IX option are as follows:

1. IX would have higher capital costs and land (space) requirements than installing GAC in existing filter boxes.
2. Accelerated testing is not practical for IX or RO/NF except for measuring RO/NF rejection. (GAC does not have that limitation.)

3. Performance characteristics on removing GenX and other PFASs at site-specific conditions are unknown. Testing/piloting is advised. (All of the options have this limitation.)
4. The media would require periodic replacement when exhausted. Testing/piloting is being considered to quantify the frequency of media replacement, which could be multiple times a year. (The GAC and IX options have this limitation. RO/NF membrane elements are generally replaced about every 7 years.)
5. The option is potentially susceptible to chromatographic peaking. Testing/piloting is advised to refine understanding. (The GAC and IX options have this limitation.)
6. Selectivity could limit removal of other PFASs even if the option is effective on GenX. (The GAC and IX options have this limitation. RO/NF could also exhibit selectivity but is anticipated to be less selective than GAC or IX.)

6.0 Reverse Osmosis or Nanofiltration Treatment Option

6.1 INTRODUCTION

Reverse osmosis (RO) and the associated nanofiltration (NF) process are membrane-based water treatment processes in which a relatively thin (1,000 Angstrom, which is equal to 0.0001 mm) and semi-permeable manufactured barrier removes dissolved materials from water. While the RO/NF process also removes particulate materials from water, it is a misapplication to use it for this purpose because particulates foul the membrane in ways that cause damage, increasing costs and shortening service life, and can result in significant reduction in plant capacity. Therefore, feedwater to RO/NF is pre-filtered including protective cartridge filtration, typically down to about the 5 micron (0.005 mm) level.

RO/NF processes are commonly applied in WTPs with applications ranging from desalination; removal of Total Dissolved Solids (TDS), sodium, chloride, etc.; softening; color removal; organics removal; and specialized applications such as removing nitrate or arsenic. For instance, CFPUA's WTP in New Hanover County applies NF to treat groundwater to remove organic materials that form DBPs when the water is chlorinated as well as softening the water at the same time.

There are some small differences between RO and NF. RO exhibits higher rejection of dissolved materials with less selectivity than NF. For example, RO might tend to provide 98 percent (nominal) rejection of both divalent and monovalent ions (such as sulfate and chloride, respectively), while NF might yield 95 percent rejection of sulfate and only 60 percent rejection of chloride. Since RO provides very high rejections for both types, it is said to exhibit little selectivity. On the other hand, for NF there is sufficient selectivity that it is difficult to generalize regarding the rejection percentages. NF rejection of inorganic solutes varies with ionic strength of the feed solution, the relative concentrations of individual ions, and sometimes as a function of pH.

For this study, the focus is on the removal of PFASs and, more specifically, on GenX. More detailed discussion on experience with RO/NF rejection of PFASs is presented in the following section. Another difference between RO and NF is that NF membrane tends to be productive at lower pressure than RO; however, in the past decade, the difference between operating pressures has been greatly reduced as newer membrane products have become available.

RO/NF membranes, as currently applied in municipal-scale water treatment projects, are manufactured in a flat sheet form that looks like a large roll of shiny white paper but is actually composed of thin layers of specially engineered plastics. The flat sheet membrane is packaged into cylindrically shaped spiral-wound filter elements that for full-scale projects are typically about 8 inches in diameter by 40 inches long. There are also smaller home-sized RO/NF elements that are about 2 inches in diameter by 12 inches long.

Home RO units generally have one element mounted in a single pressure vessel, installed under a sink, and are operated on the available pressure from the community's distribution system. On full-scale systems, multiple elements are mounted inside each pressure vessel, and many pressure vessels are included in each train. Unlike home systems, pumping is used in full-scale facilities to provide the driving pressure, and antiscalant chemicals are added to the feedwater to allow as much water recovery as possible (to minimize the waste discharge flow) without allowing precipitation to occur that could damage the membrane. Periodically, the operators conduct cleaning cycles to maintain capacity at as low an energy consumption as possible.

While many water treatment processes have an influent and an effluent, RO and NF have three process streams flowing while in operation: the influent (which is called the feed) and two effluent streams, the permeate (which is the purified water) and the concentrate (which is the concentrated wastewater). RO/NF are so effective at removing dissolved materials that frequently only a portion of the finished water is made up of permeate, and the rest is bypassed around the RO/NF. However, a preliminary evaluation of the GenX application indicates that 100 percent of the finished water would likely have to be permeate.

Depending on the concentrations and treatment goals, it is even possible that a second pass of RO would be needed to sufficiently remove GenX. In that case, this application of RO/NF would be more like seawater desalination facilities, where at least one 100 percent first pass is applied, and in some cases, a second pass or a partial second pass is also applied. In addition, many seawater RO facilities need and practice post-treatment to add some hardness, alkalinity, and sometimes other constituents back into the permeate water before distribution to make the water noncorrosive; it is highly likely that would also be needed in this case.

Major variables to consider with RO/NF are parameters called rejection, recovery, operating pressure, and flux. Rejection describes the percent of a given component in the feed that is not passed to the permeate. For example, if there is 97 percent rejection of sodium and a concentration of 100 mg/L in the feed, the permeate concentration would be 3 mg/L. Recovery is the percent of feedwater that becomes permeate. The goal is to maximize the recovery to minimize the flow rate of concentrate to waste, but a high value cannot be arbitrarily selected. Recovery is determined after careful calculations considering the site-specific maximum concentration that can be achieved without precipitation occurring inside the RO/NF system. Operating pressure is generally calculated according to the water chemistry and temperature as well as certain aspects of the selected membrane and the system design.

Flux is an important parameter that is determined by past experience with RO/NF, frequently augmented by some site-specific testing, especially for surface water applications such as this one. Flux is the RO/NF equivalent of hydraulic loading rate. With GAC and conventional granular media filters, the loading rate is typically the filtered water flow rate in gpm divided by the cross-sectional area of the filter in ft^2. For RO/NF, the flux is the permeate flow rate in gpd divided by the membrane area in ft^2. The unit of measurement for flux, gpd/ft^2, is typically abbreviated as gfd. As with recovery, the value for flux cannot be arbitrarily selected. If the flux is set too high for a given application, excessive and costly fouling and operational problems will occur at the facility. In the more extreme cases of high flux, the capacity of the facility has to be lowered to yield stable performance.

6.2 APPLICATION TO PFAS

Experience with removing PFASs with RO/NF is summarized in this section.

Steinle-Darling and Reinhard (2008) measured rejection of various PFASs, but not GenX, by four different NF membranes in a small flat sheet test device. Testing was primarily conducted with Dow/FilmTec NF270 with some experiments also performed with Dow/FilmTec 200 or the GE/Osmonics DK or DL membranes. It should be noted that these are piperazine-based polyamide membranes, which are somewhat different from the polyamide type chemistry used in the more widely applied RO and NF membranes. In addition, these tests were conducted on a small flat sheet device, which tends to yield higher rejection values than full-scale two- or three-stage systems with spiral-wound elements that are operated at higher recovery, so the concentration on the feed-concentrate side is higher. Summarizing the results, many PFASs with a molecular weight above

300 Daltons had at least 95 percent rejection. Charge on the solutes and operating pH had an impact for some compounds. For example, one solute with a molecular weight of 499 Daltons that was uncharged at the operating pH, exhibited lower rejection, as low as 42 percent with one of the tested membranes. Sorption of some compounds was also observed on the membrane, and, because this could lead to misleading results, future testing should address that issue. Ionic strength had little impact on rejection of PFASs, which was shown by adding 2,500 mg/L of sodium chloride to the feed solution, and, which resulted in less than a 1 percent change in rejection. Fouling impacted rejection; average rejections for clean membrane were 99 percent but were only 95 percent for fouled membrane.

The literature review by Dickenson and Higgins (2016) described the work by Steinle-Darling and Reinhard (2008), which is discussed above, and Tang et al. (2006) who observed greater than 99 percent removal of PFASs (in that case PFOS) with four different types of RO membrane.

Dickenson and Higgins (2016) also conducted trials with Dow/FilmTec NF270 membrane. They used flat sheet test cells, such as those used by Steinle-Darling and Reinhard (2008), but with modifications to address certain issues. For example, they used a larger feed volume with once-through flow, rather than recycle, and two test cells in series to provide experimental duplication. For all of the PFASs included in this study, rejection exceeded 93 percent and mostly exceeded 95 percent. Dickenson and Higgins compared clean to fouled membrane and did not observe lower rejection with fouled membrane; in some sampling events, the rejection increased with fouling.

Dickenson and Higgins (2016) also evaluated performance at two full-scale potable reuse facilities using RO, one with Hydranautics ESPA2 spiral-wound elements arranged in a three-stage array operated at a flux of 12 gfd and 85 percent recovery and the other with Toray and Hydranautics spiral-wound elements at a flux of 11.6 to 11.9 gfd and 80 percent recovery. All PFASs were below detection in the RO permeate samples. Concentrations in the influent of some PFASs as high as 370 ng/L and RO permeate concentrations of less than 0.5 ng/L were reported in the appendix indicating better than 99 percent rejection.

One of the largest RO/NF membrane manufacturers, Toray (personal communication) reported that testing with a PFAS that is similar to GenX (which they described as being PFHxA with the following formula, $C_6HF_{11}O_2$) resulted in RO rejection normally higher than 94 percent but lower at lower pH values (which were not quantified), and NF with a rejection of about 70 percent.

6.3 ADVANTAGES

Advantages of the RO/NF option are as follows:

1. RO/NF probably (subject to confirmation) removes the widest range of PFAS chemicals with the least selectivity and without chromatographic peaking.
2. CFPUA has experience operating NF at another facility.
3. All of these options have the advantage of having been applied in a wide range of WTPs, albeit for different applications than this.

6.4 LIMITATIONS

Limitations of the RO/NF option are as follows:

1. RO/NF may have (subject to confirmation) the highest capital costs and greatest land (space) requirements of these options.
2. To maintain the existing WTP's rated capacity, using the RO/NF option would require an increase to the regulator-approved loading rate of the existing filters or the addition of more filters.
3. Additional treatment might be needed to sufficiently treat the water to avoid RO/NF fouling; however, the existing WTP's relatively low filtered water turbidity indicates this may not be needed (subject to confirmation).
4. Performance characteristics on removing GenX and other PFASs at site-specific conditions are unknown. Testing/piloting is advised. (All of the options have this limitation.)
5. RO/NF continually generates a liquid waste stream requiring disposal. This could be a major and potentially costly issue if direct discharge is not allowed.
6. RO/NF is energy intensive (would have the highest energy consumption).
7. RO/NF removes such a wide range of solutes from the water that post-treatment of the finished water would be needed to add certain minerals back into the water to prevent corrosion in the distribution system and customers' homes. This step would be necessary to prevent problems such as "red" water or elevated levels of lead and/or copper.
8. Depending on the influent concentrations, effluent goals, and rejection performance, RO/NF may need a second pass or a partial second pass, which would further increase costs.
9. During testing/piloting of RO/NF, it is recommended that measurements include concentrations of targeted organic chemicals (e.g., GenX and other PFASs) in feed and concentrate as well as permeate to allow mass balance calculations to verify that rejection is providing all of the observed removal, not a shorter term adsorption mechanism. Without that information, the projection of long-term performance could be misleading.

7.0 Discussion

The location for each of the options within the Sweeney WTP's process schematic is shown on Figure 7-1. Two locations for suboptions are shown for GAC: (1A) with new GAC media installed in the existing filter-adsorber boxes and (1B) with the GAC installed in new contactors that would treat effluent from the existing filter boxes. Both of the other options (Option 2, IX, and Option 3, RO/NF) would treat effluent from the existing filter boxes. The location shown on the figure (for Options 1B, 2, and 3) is immediately following the existing filters, but the treatment would be just as effective if it were located downstream from the existing UV units. Selection of the location could be made during a subsequent design phase according to plant hydraulic and space issues. The post-filtration options include the assumption that the filters provide sufficient pretreatment, which can be confirmed in site-specific testing.

Schematic diagrams of the options are shown on Figure 7-2.

Of the two GAC options, 1A would be the lower cost option if suitable operating conditions and performance with a sufficient number of BV before change-out can be determined for GAC installed in the existing filters. In some cases, GAC media is more effective when applied to filtered water only as an adsorber. It is possible when used as both a filter and an adsorber that the service life of the media can be shortened by backwashing cycles. The filter-adsorber needs fairly frequent backwashing to remove accumulated solids material; when the GAC is applied as an adsorber only, backwashing is infrequent. Pilot testing could be conducted to determine the difference in performance (BV to breakthrough) in this case.

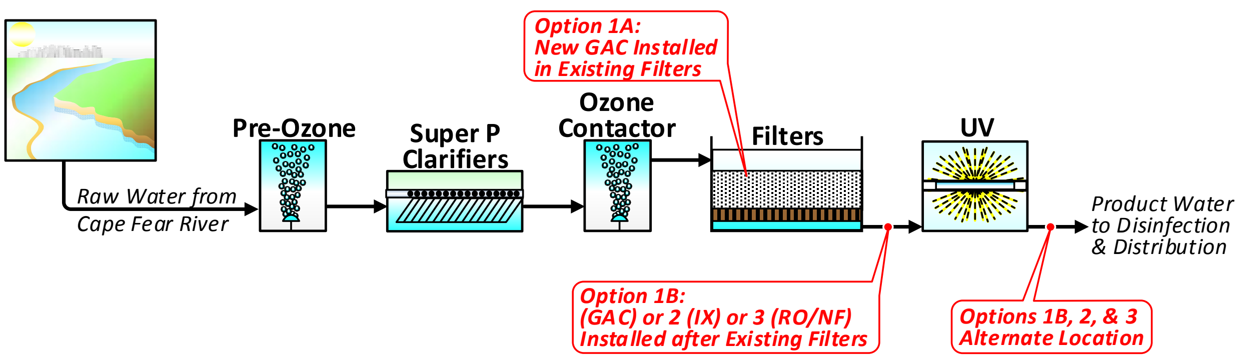

Figure 7-1 Process Schematic Showing the Potential Locations of New Options at the Existing Sweeney WTP

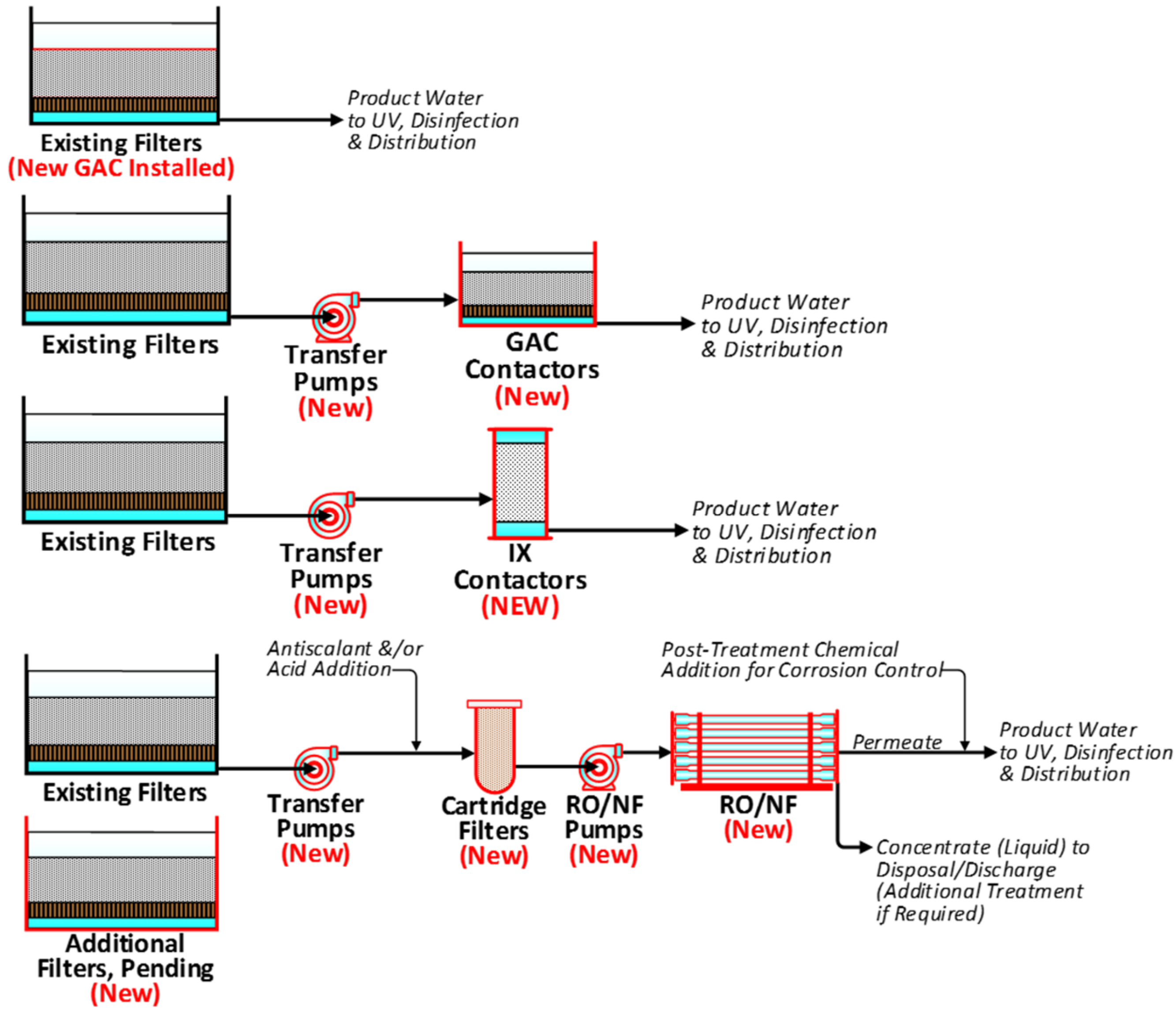

Figure 7-2 Schematic Diagrams of New Options

A comparison of the main features of the treatment methods is summarized in Table 7-1. These rankings incorporate engineering assumptions that are based on the currently available information. It is anticipated that additional information would be collected as the project moves forward.

Table 7-1 Comparison of Treatment Methods (5 is Best)

PARAMETER	GAC IN FILTERS	GAC ADSORBER	IX	RO/NF
OPTION NUMBER	1A	1B	2	3
Known Performance on GenX and other PFAS	0	0	0	0
Potential on GenX and other PFAS	5	5	5	5
Commonly Used for Water Treatment	5	5	5	5
Capital Cost	5	3	3	1
Implementation Time	5	2	2	1
Liquid Waste	5	5	5	1
Energy Use	5	4	4	1
Labor	5	3	3	1
Rerating Existing Filters	5	5	5	1
Selectivity	1	1	1	5
Chromatographic Peaking	1	1	1	5
Operational Understanding	5	5	2	4
Rapid Test Option	5	5	1	1

Notes related to the table are as follows:

- RATINGS – The ratings are comparative and are expressed on a 0 to 5 scale with 5 being the highest, best rating in each category.
- KNOWN PERFORMANCE ON GENX AND OTHER PFAS– All options were rated the same, a low rating, because there is little information available on water treatment methods to remove GenX.
- POTENTIAL ON GENX AND OTHER PFAS – All options were rated the same, a high rating, because the available information available indicates that any of these methods would be effective at removing GenX.
- COMMONLY USED - All options were rated the same, a high rating, because all of these treatment methods are commonly used in drinking water treatment facilities.
- CAPITAL COST – Option 1A is the best in this category because there would be no new capital cost for installing new GAC in the existing filters. However the life cycle costs could be high if the GAC would require frequent replacement. Regarding the other options, adding GAC adsorbers or IX beds (1B and 2) would qualitatively have lower capital costs than RO/NF (3).

- IMPLEMENTATION TIME – Option 1A (replacing the GAC in the existing filters) could be implemented in the shortest amount of time. Regarding the other options, adding GAC adsorbers or IX beds (1B and 2) would take somewhat less time to build and install than RO/NF (3).

- LIQUID WASTE - Neither GAC nor IX would generate significant additional liquid waste and the spent material would be shipped off-site for regeneration or disposal. RO/NF continuously yields a liquid waste stream, the concentrate. Handling and disposal of this stream can be problematic and sometimes costly.

- ENERGY USE - New GAC in the existing filters (1A) would not increase the WTPs energy usage. New post-filtration GAC or IX systems (1B or 2) would require some additional pressure drop. RO/NF is the highest energy user of these options.

- LABOR - Applying GAC in the existing filter boxes would have minimal impact. New facilities for post-filtration GAC or IX systems (1B or 2) would likely require some additional staff. Experience with RO/NF that option would require more additional staff.

- RERATING EXISTING FILTERS – The RO/NF option would require a higher filtered water flow rate and so would need either an increased loading rate on the existing filters or additional (new) filters. Neither GAC or IX options would require an increase in filtered water capacity.

- SELECTIVITY - While site-specific testing would be needed to fully show this, in general RO/NF removes a wider range of compounds. GAC and IX are more selective.

- CHROMATOGRAPHIC PEAKING - Chromatographic peaking can occur with GAC and IX and that has been indicated in similar applications. If it occurs, then during breakthrough some concentrations are higher in the effluent (the treated water) than in the influent. Since the removal mechanism of RO/NF is rejection, not adsorption, then it would not occur with RO/NF. RO/NF can experience increased passage due to leaks in seals but that is repairable.

- OPERATIONAL UNDERSTANDING - GAC scores best in this category because the existing Sweeney WTP uses GAC. The utility has NF at another location and so their operators also have an understanding of that treatment process, but the Sweeney operators do not have day-to-day experience.

- RAPID TEST OPTION - GAC is the only option with an accepted rapid/accelerated testing method, which is called RSSCT.

8.0 Summary/Recommendations

1. A number of perfluorinated compounds have been observed in the Cape Fear River upstream from the intake of the Sweeney WTP. Researchers measured average GenX concentrations of 631 ng/L. GenX is one of a group of organic chemicals that are referred to as PFASs, which are used in a wide variety of manufactured products.
2. Neither the EPA nor NC DEQ have set enforceable MCLs for GenX or other PFASs. Because of concern over potential adverse health effects associated with the presence of these compounds in drinking water, CFPUA is proactively considering the feasibility and effectiveness of treatment alternatives.
3. Chemours, a company that had been discharging wastewater containing GenX and PFAS into the Cape Fear River announced in late June 2017 that it had stopped discharging wastewater containing GenX while determining how to address the issue. Even if GenX discharge is not restarted, it is anticipated that concentrations of a stable chemical such as GenX may remain in the river for a period of time. It appears that Chemours may be continuing to discharge wastewaters containing PFAS compounds; information to revise that possibility has not been found.
4. A study of full-scale water treatment systems has shown that conventional water treatment methods, including aeration, chlorination, chloramination, chlorine dioxide, coagulation, flocculation, anthracite media filtration, microfiltration or ultrafiltration, ozonation, permanganate addition, sedimentation, softening (caustic softening followed by solids contact clarification), and UV light, were not effective at removing PFASs.
5. Various researchers have found that GAC, IX, and RO/NF are treatment options that have been successful at removing PFASs but that information is limited; almost no information is available on applying water treatment processes specifically to GenX removal.
6. Site-specific testing of these processes is recommended to refine the understanding of design and operational parameters for GAC, IX, and RO/NF.
7. Since the lowest initial cost option would be Option 1A, installing new GAC media into the existing filters, one logical approach would be to conduct testing to verify the viability of that option before staring a larger testing program. A key parameter for Option 1A is replacement frequency, which is directly related to the number of BV that can be achieved by the GAC before breakthrough. For example, even though Option 1A would have no capital cost, it would be too expensive and impractical if the GAC had to be replaced weekly or daily. Another important parameter is the range of PFASs that are removed by each option. For example, the data available from other sites indicate that the highest capital cost option, RO/NF, may provide removal of a longer list of PFAS compounds than GAC or IX. Testing would quantify these and other parameters and provide a basis for decision-making.
8. As a parallel path activity while testing proceeds, it is recommended that preliminary, planning-level, cost opinions be developed for the likely lowest cost and highest cost options to assist the utility with planning. Initially, before testing has been conducted, the development of the cost opinions would be based on preliminary assumptions that could subsequently be revised when test results are available. The low and high cost options would be, respectively, Option 1A (new GAC media installed in the existing filters) and Option 3 (RO/NF).

9.0 List of Abbreviations

AIX	Anionic Ion Exchange
BV	Bed Volume
CAS	Chemical Abstracts Service
CFPUA	Cape Fear Public Utility Authority
cm	Centimeter
DBP	Disinfection Byproducts
EBCT	Empty Bed Contact Time
EPA	United States Environmental Protection Agency
ft^2	Square Foot
GAC	Granular Activated Carbon
gfd	Gal per ft^2 per day = gpd/ft^2
gpm	Gallon per Minute
IX	Ion Exchange
LR	Loading Rate
MCL	Maximum Contaminant Level
mg/L	Milligrams per Liter
mgd	Million Gallons per Day
NC DEQ	North Carolina Department of Environmental Quality
NF	Nanofiltration
ng/L	Nanogram per Liter
NTU	Nephelometric Turbidity Unit
PAC	Powdered Activated Carbon
PFAS	Perfluoroalkyl Substance
PFBA	Perfluorobutanoic Acid
PFBS	Perfluorobutane Sulfonate
PFC	Perfluorinated Compound
PFHxA	Perfluorohexanoic Acid
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulfonate
PFPeA	Perfluoropentanoic Acid
PFPrOPrA	Perfluoro-2-Propoxypropanoic Acid
RO	Reverse Osmosis

RSSCT	Rapid Small-Scale Column Test
TOC	Total Organic Carbon
μS/cm	Micro-Siemens per Centimeter
UV	Ultraviolet
WTP	Water Treatment Plant

10.0 References

Black & Veatch Project 145726, Process Design Memorandum for Sweeney WTP Expansion, February 16, 2007.

Black & Veatch Project 145726, Civil Design Memorandum for Sweeney WTP Expansion, May 22, 2007.

Carter, K. E., and Farrell, J. (2010). Removal of Perfluorooctane and Perfluorobutane Sulfonate from Water via Carbon Adsorption and Ion Exchange, Separation Science and Technology 45(6): 762-767.

Deng, S., Yu, Q., Huang, J., and Yu, G. (2010). Removal of Perfluorooctane Sulfonate from Wastewater by Anion Exchange Resins: Effects of Resin Properties and Solution Chemistry, Water Research 44(18): 5188-5195.

Dickenson, Eric R. V., and Christopher Higgins (2016). Treatment Mitigation Strategies for Poly- and Perfluoroalkyl Substances, WEF Proj 4322, ISBN 978-1-60573-234-3, Water Research Foundation, Denver, Colorado.

EPA (2016). Fact Sheet PFOA and PFOS Drinking Water Health Advisories, EPA 800-F-16-003, November 2016.

Eschauzier C., Beerendonk E., Scholte-Veenendaal P., and De Voogt P. (2012). Impact of Treatment Processes on the Removal of Perfluoroalkyl Acids from the Drinking Water Production Chain, Environmental Science & Technology 46(3): 1708-15.

GenX Wastewater, DEQ, June 27, 2017.

Heydebreck, F., Tang, J., Xie, Z., and Ebinghaus, R. (2015). Alternative and Legacy Perfluoroalkyl Substances: Differences Between European and Chinese River/Estuary Systems, Environmental Science & Technology 49(14): 8386-8395.

Houde, M., Martin, J. W., Letcher, R. J., Solomon, K. R., and Muir, D. C. (2006). Biological Monitoring of Polyfluoroakyl Substances: A Review, Environmental Science & Technology 40(11): 3463-3473.

Lampert, D., Frisch, M., and Speitel, G. (2007). Removal of Perfluorooctanoic Acid and Perfluorooctane Sulfonate from Wastewater by Ion Exchange, Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management. January 11(1) 60-68.

Mordock, Jeff (2017). "Chemours says it has stopped GenX discharge at North Carolina plant," The News Journal, June 27, 2017. http://www.delawareonline.com/story/money/2017/06/27/chemours-says-has-stopped-genx-leak-north-carolina-plant/431499001/

North Carolina Department of Environmental Quality, "DEQ Verifies Chemours Has Stopped Discharging." https://deq.nc.gov/deq-verifies-chemours-has-stopped-discharging-genx-wastewater

Post, G., Louis, J., Cooper, K., Boros-Russo, B., and Lippincott, R. (2009). Occurrence and Potential Significance of Perfluorooctanoic Acid (PFOA) Detected in New Jersey Public Drinking Water Systems, Environmental Science & Technology 43(12): 4547-4554.

Quiñones, O., and Snyder, S. (2009). Occurrence of Perfluoroalkyl Carboxylates and Sulfonates in Drinking Water Utilities and Related Waters from the United States, Environmental Science & Technology 43(24): 9089-9095.

Redding, Adam (2017). Selection of activated carbon for PFOA/PFOS removal, NEWWA Spring Conference, April 5, 2017.

Senevirathna, S. T. M. L. D., Tanaka, S., Fujii, S., Kunacheva, C., Harada, H., Shivatoki, B. R., and Okamoto, R. (2010). A Comparative Study of Adsorption of Perfluorooctane Sulfonate (PFOS) onto Granular Activated Carbon, Ion-Exchange Polymers and Non-Ion-Exchange Polymers, Chemosphere 80(6): 647-651.

Sun, M., Arevalo, E., Strynar, M., Lindstrom, A., Richardson, M., Kearns, B., Pickett, A., Smith, C., and Knappe, Detlef R. U. (2016). Legacy and Emerging Perfluoroalkyl Substances are Important Drinking Water Contaminants in the Cape Fear River Watershed of North Carolina, Environmental Science & Technology Letters 3(12): 415-419, American Chemical Society.

Takagi, S., Adachi, F., Miyano, K., Koizuma, Y., Tanaka, H., Mimura, M., Watanabe, I., Tanabe, S., and Kannan, K. (2008). Perfluorooctanesulfonate and Perfluorooctanoate in Raw and Treated Tap Water from Osaka, Japan, Chemosphere 72: 1409-1412.

Water Research Foundation, WRF (2016). Poly- and perfluoroalkyl substances: background technical information, 5 pp., Water Research Foundation, Denver, Colorado.

Yu, Q., Zhang, R., Deng, S., Huang, J., and Gang, Y. (2009). Sorption of Perfluorooctane Sulfonate and Perfluorooctanoate on Activated Carbons and Resin: Kinetic and Isotherm Study, Water Research 43: 1150-1158.

TECHNICAL MEMORANDUM 2

Preliminary Report on Prescreened Alternatives – GenX and Other PFAS Treatment Options Study

B&V PROJECT NO. 196369

NORTH CAROLINA PROFESSIONAL SEAL 8749 ENGINEER H. KEITH PROFFIT

K K Proffit

9/25/17

PREPARED FOR

Cape Fear Public Utility Authority

SEPTEMBER 2017

BLACK & VEATCH

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Executive Summary

Organic chemicals known as perfluoroalkyl substances (PFASs) have been detected in Cape Fear River water, which supplies the Sweeney Water Treatment Plant (WTP), as discussed in Technical Memorandum 1 (TM1), Black & Veatch (2017). PFAS compounds, including one called GenX, were identified in research by Dr. Knappe, a professor at North Carolina State University and coauthors (Sun et al. 2016). These compounds have also been detected by the North Carolina Department of Environmental Quality (NCDEQ); recent sampling indicates the concentrations have declined. Because of widespread use, most people have been exposed to PFASs, which have been found in waters worldwide. Neither the Environmental Protection Agency (EPA) nor the NCDEQ have set enforceable maximum contaminant levels (MCLs) for GenX or other PFASs. Because of concern over potential health effects, Cape Fear Public Utility Authority (CFPUA) is proactively considering the feasibility and effectiveness of treatment alternatives. CFPUA is one of the first utilities within the United States to pursue enhanced treatment to target removal of these compounds.

This TM presents planning level opinions of probable cost for treatment options previously selected in TM1. These are summarized in Table ES-1.

Table ES-1 Summary of Planning Level Cost Opinions

PARAMETER	OPTION 1A	OPTION 1B	OPTION 1C	OPTION 3
Description	GAC in Existing Filters	GAC Contactors Post-Filtration	Deep Bed Version of 1B	RO/NF Post-Filtration
Initial Cost, $ in millions	$1.7 million	$28 million	$32 million	$113 million
Annual Operating Costs, $ in millions/yr	$3.0 million to $6.0 million	$3.3 million to $6.3 million	$3.4 million to $6.4 million	$3.3 million
Present Worth (PW) of Annual Costs, $ in millions	$42 million to $82 million	$45 million to $86 million	$46 million to $86 million	$45 million
Total Present Worth (TPW), $ in millions	$44 million to $84 million	$73 million to $114 million	$78 million to $118 million	$158 million

Notes: GAC = Granular Activated Carbon; RO/NF = Reverse Osmosis/Nanofiltration

Option 1C was added after TM1 was written. Option 1C is a deeper bed version of Option 1B.

Option 1A's initial cost includes an initial load of GAC media and one-time replacement of sand and gravel. The GAC options (1A, 1B, 1C) would have higher initial costs if standby filters/contactors were added to provide full capacity when units are off-line during GAC replacement events.

Annual costs for the GAC options (1A, 1B, 1C) are a function of media life. The cost ranges in the table are based on 6,000 and 12,000 bed volumes (BV). A 6,000 BV case would need to change GAC twice as often as a 12,000 BV case. CFPUA is conducting testing to determine BV at Cape Fear River concentrations.

In accordance with recommendations in TM1, a detailed cost opinion was not prepared for Option 2, Ion Exchange (IX); however, it is the engineer's opinion that TPW for Option 2 would be roughly in line with Option 1B. IX is less widely practiced for organic contaminant removal than GAC or RO/NF. However, recent pilot testing elsewhere of IX resins has shown promise as a treatment technology for removal of perfluorinated compounds from drinking water. Therefore, as a contingency CFPUA is conducting IX testing.

Summarizing key issues related to each option:

- Option 1A (New GAC in Existing Filters). This is the lowest cost option due to the comparatively low initial cost. Currently the GAC media in the existing filters provides filtration, while if new GAC were installed it would provide both filtration and adsorption to remove dissolved organic materials. A key issue with all of the GAC options (1A, 1B, and 1C), is the change-out frequency. Testing is being conducted to verify preliminary assumptions. At the 6,000 BV to 12,000 BV cases considered herein, change-out would be every 78 days to 156 days for each unit. Such frequent servicing would reduce plant capacity, unless standby filters are added and could be an impediment to operations. Other aspects of GAC options (1A, 1B, and 1C) that can also be tested include a risk of chromatographic peaking (which could result in higher concentrations in the effluent than in the influent) and a benefit of removing other compounds such as Contaminants of Emerging Concern (CEC) or Pharmaceuticals and Personal Care Products (PPCP).

- Option 1B (GAC Contactors Post-Filtration). This option is similar to Option 1A, since both apply GAC; however, 1B has the added feature of locating the new process downstream from the filters. Therefore, while the frequency of GAC change-outs could be an impediment to the operations staff for 1A, 1B or 1C, GAC replacement events would not directly impact filtration activities with 1B or 1C. The GAC in Option 1B/C would remove organic materials via adsorption, but it would not also provide filtration; that would continue to be accomplished by the existing filters. As with Option 1A, 1B/C would provide the benefit of removing other CEC and PPCP compounds. If adsorption were not needed in the future, the change-out frequency of 1A could be essentially eliminated while with Options 1B/C the contactors could subsequently be converted to use as filters, such as for a plant expansion.

- Option 1C (Deep Bed Version of 1B). Option 1C, a deep bed version of Option 1B, was included to consider the cost impact of contactors with a longer time period between breakthrough and therefore a longer time between GAC replacement events. Due to increased construction costs and a greater amount of GAC media initially installed, the capital costs of 1C would be higher than with 1B; however, the operating costs would be essentially the same, since the consumption of GAC would be constant. Having longer time periods between GAC replacement events would be less disruptive to plant operations.

- Option 2 (IX Post-Filtration). There are similarities between Option 2 (IX) and the post-filtration GAC options (1B and 1C), including operating costs affected by the number of BV and the associated frequency of media replacement. Testing is being conducted to allow comparison of the number of BV for GAC and IX media and better quantification of costs.

- Option 3 (RO/NF Post-Filtration). Option 3 has the highest costs, both initial and total present worth, as well as requiring the greatest amount of land. The evaluation indicates that the main RO/NF building would not fit on the existing Sweeney WTP site. An alternative location to consider would be the park area to the south adding to the complexity of the project. It is unknown if that land would be available for this purpose. In addition, Option 3 includes the drawbacks of consuming the greatest amount of raw water, disposal of the concentrate stream and post-treatment to control corrosion. The additional raw water consumption could limit future plant expansion options and the concentrate disposal could increase the projected cost opinion, depending on the requirements of the regulatory agency. The costs for a concentrate disposal method have been included in the evaluation, but it is unknown at this time if the regulatory agency will accept this method.

1.0 Purpose

This document presents opinions of probable cost for water treatment methods that were previously identified in Technical Memorandum 1 (TM1), Black & Veatch (2017), for the removal of the anthropogenic (human-made) organic chemicals known as perfluoroalkyl substances (PFASs), including a type called GenX. It is important to note that GenX has only recently been identified as a concern within the field of drinking water treatment. Only limited information is available on treatment methods to remove GenX and other PFASs. The evaluation presented in this memorandum is based on engineering assumptions and extrapolations that could be confirmed by subsequent bench-scale and/or pilot-scale testing before full-scale implementation. Given the preliminary nature of these treatment concepts, the type of cost opinion presented herein is referred to as Class 5 by the Association for the Advancement of Cost Engineering (AACE), which can be applied to a planning level comparison of options.

2.0 Introduction

2.1 GENERAL INTRODUCTION

There is a group of anthropogenic (human-made) organic chemical compounds, collectively referred to as perfluoroalkyl substances (PFASs); also sometimes called perfluorinated compounds (PFCs). The term PFAS is used in this memorandum. As discussed in TM1, Black & Veatch (2017), and various additional references (including Dickenson and Higgins 2016, Sun et al. 2016, and Water Research Foundation 2016), PFASs have been used in a variety of manufactured products such as firefighting foams, carpets, clothing, cosmetics, food packaging, and cookware. Because of their widespread use, most people have been exposed to PFASs. PFASs have been found in many types of waters worldwide, including the United States, Germany, Canada, South Korea, China, Brazil, United Kingdom, France, Italy, and Spain.

One specific type of PFAS of special interest to Cape Fear Public Utility Authority (CFPUA), which is known by the trade name GenX, was detected by Sun et al. (2016) in the Cape Fear River at an average concentration of 631 nanograms per liter (ng/L). Chemically GenX is known as Perfluoro-2-Propoxypropanoic Acid (PFPrOPrA). More recently, the North Carolina Department of Environmental Quality (NCDEQ) reported that river water samples from the July 17 to 20, 2017 time period had GenX concentrations below 140 ng/L (https://deq.nc.gov/news/hot-topics/genx-investigation/genx-sampling-sites). On Sept 13, 2017 CFPUA reported results (http://www.cfpua.org/CivicAlerts.aspx?AID=741) from 17 sample days between Aug 7 and 28, 2017 of raw and finished water at the Sweeney WTP with GenX concentrations in the 32 ng/L to 54 ng/L range. Previously, on June 27, 2017, NCDEQ confirmed that Chemours had stopped discharging GenX wastewater to the Cape Fear River (https://deq.nc.gov/deq-verifies-chemours-has-stopped-discharging-genx-wastewater). The results indicate that without continued discharge of GenX the concentration in the river is declining.

2.2 REGULATORY HISTORY

Allowable concentration of PFAS in drinking water is a relatively new topic being considered by the United States Environmental Protection Agency (EPA). The EPA has not issued any regulations regarding PFASs in drinking water; therefore, there are no enforceable maximum contaminant levels (MCLs) for PFASs. However, in 2009, on the basis of the limited health effects information available at that time, the EPA published provisional health advisories for two PFAS compounds: perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS). In May 2016, the EPA issued revised health advisories for PFOA and PFOS of 70 ng/L, measured either individually or in combination (EPA 2016). The EPA develops health advisories to provide information on contaminants that it believes may cause human health effects and are known or anticipated to occur in drinking water. These health advisories are "non-enforceable and non-regulatory and provide technical information to states agencies and other public health officials" (EPA 2016). There are currently no EPA regulations or health advisories regarding GenX. Although there are no enforceable MCLs for GenX or other PFASs, the CFPUA is proactively considering the feasibility and effectiveness of treatment alternatives because of concern over potential adverse health effects associated with the presence of these compounds in drinking water. CFPUA is one of the first utilities within the United States to pursue enhanced treatment that targets removal of these compounds.

2.3 TREATMENT METHODS

TM1, Black & Veatch (2017), presented additional information on PFASs including a preliminary evaluation of treatment methods. A summary of TM1 is presented in the next section of this memorandum.

3.0 Summary of Initial Process Evaluation from TM1

The following is a summary of the recommendation in TM1, Black & Veatch (2017) that provides a preliminary evaluation of treatment methods:

1. Perfluorinated compounds, including one called GenX, have been observed in the Cape Fear River upstream from the intake of the Sweeney Water Treatment Plant (WTP).
2. Neither the EPA nor NCDEQ have set MCLs for GenX or other PFASs. Because of concern over potential adverse health effects associated with the presence of these compounds in drinking water, CFPUA is proactively considering treatment alternatives.
3. Chemours, a company that had been discharging wastewater containing GenX and PFAS into the Cape Fear River, announced in late June 2017 that it had stopped discharging wastewater containing GenX while determining how to address the issue.
4. A study of full-scale water treatment systems has shown that conventional water treatment methods, including aeration, chlorination, chloramination, chlorine dioxide, coagulation, flocculation, anthracite media filtration, microfiltration or ultrafiltration, ozonation, permanganate addition, sedimentation, softening (caustic softening followed by solids contact clarification), and ultraviolet (UV) light, were not effective at removing PFASs.
5. Various researchers have found that granular activated carbon (GAC), ion exchange (IX), and reverse osmosis or nanofiltration (RO/NF) are treatment options that have been successful at removing PFASs, but performance information is limited. Site-specific testing of selected processes is recommended before developing a detailed design.
6. Process schematics of the evaluated options are shown on Figures 3-1 and 3-2.
7. TM1 recommended that planning-level cost opinions be developed for the likely lowest and highest cost options to assist the utility with planning. Since site-specific testing has not been completed, these cost opinions would be based on preliminary assumptions and past research. The low and high cost options would be Option 1A (new GAC media installed in the existing filters) and Option 3 (RO/NF located downstream from the existing filters).

Therefore, this memorandum, TM2, presents cost opinions for Options 1A and 3. In addition, Option 1B (GAC contactors located downstream from the existing filters) and a deeper bed version of 1B, referred to as Option 1C, are also considered in TM2.

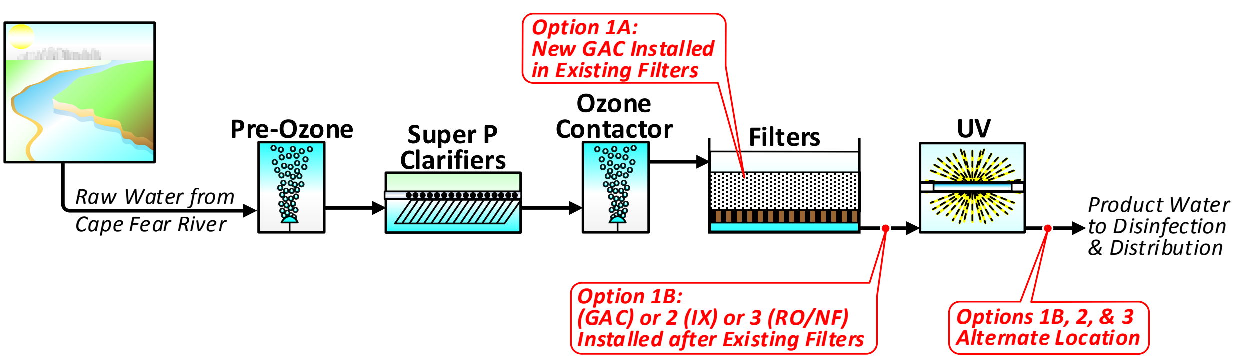


Figure 3-1 Process Schematic Showing Potential Locations of TM1 Options at the Existing Sweeney WTP

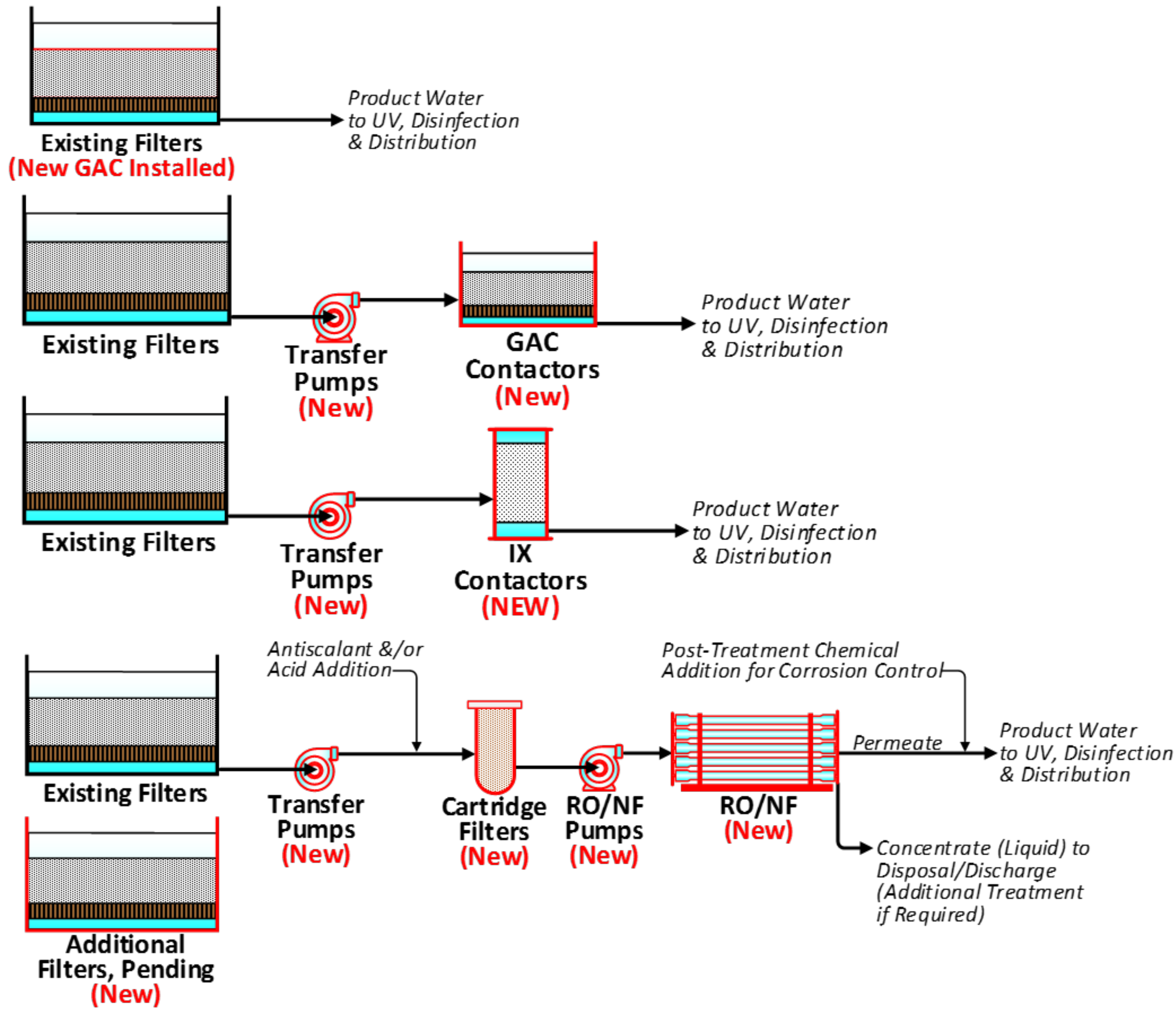


Figure 3-2 Schematic Diagrams of Options Evaluated in TM1

Options shown on Figure 3-2 (from top to bottom) are as follows:

- Option 1A (New GAC media installed in the existing filters).
- Option 1B (GAC contactors located downstream from the existing filters).
- Option 2 (IX located downstream from the existing filters).
- Option 3 (RO/NF located downstream from the existing filters).

An option that was not considered in TM1 is a deeper bed version of Option 1B, which is referred to in TM2 as Option 1C. Diagrams showing process location and a schematic for the 1C option would be the same those shown for Option 1B.

4.0 Calculation Basis

The overall calculation basis applied in this memorandum is presented in Table 4-1. Items specifically related to individual options are presented in the section on each option.

Table 4-1 Overall Calculation Basis

PARAMETER	UNITS	VALUE
Design Capacity (Basis for capital costs)	mgd	35
Average Day Capacity (Basis for operating costs)	mgd	14 (Average day flow for 2014 to 2016)
Peak Flow Day in 2016	mgd	26
Operating Period	years	20
Interest Rate (Basis for converting annual costs to present worth)	percent	4
New Process Area Costs, Outside/Covered	$\$/ft^2$	50
New Building Costs (Taller Option 1C Building)	$\$/ft^2$	200 (220)
Cost of Electricity	$/kWh	0.055 (Based on April 2017 electrical bill)
Additional Staff	$/yr	$50,000 x 1.4 factor to include benefits = $70,000
Contingency (Included in opinions of capital costs)	percent	30

The capital cost opinions presented in this TM are based on Black & Veatch experience and its proprietary cost development tool. After determining an installed equipment cost, additional project costs are added on the basis of an additional 29.5 percent factor to include sitework, yard piping, and on-site infrastructure for electrical and instrumentation/controls; an additional 26 percent factor to include contractor/subcontractor markups (e.g., overhead, profit, mobilization, bonds, and insurance); and non-construction costs are included on the basis of an additional 49.5 percent factor to provide budgets for permitting, engineering/design, legal and administrative, construction services, commissioning and start-up, and contingency.

5.0 Option 1A (New GAC Installed in the Existing Filters)

The calculation basis for Option 1A (New GAC Installed in the Existing Filters) is presented in Table 5-1. The existing filters currently include GAC media, but the adsorptive capacity of that media has been exhausted over time. The currently installed media provides filtration. If new GAC media were installed, the filters would provide both filtration (e.g., removing particles and turbidity) and adsorption (e.g., removing certain dissolved materials). The design and operating parameters for 1A (capacity, loading rate, and pressure drop) were assumed to be the same as currently practiced at the existing Sweeney WTP. The number of bed volumes (BV) until breakthrough occurs directly impacts replacement frequency. Assumptions based on experience with GAC at other locations have been included in Table 5-1 and in the evaluation. Testing is being conducted to verify the BV value for this specific source water with different types of GAC. Site-specific verification is needed because the types and concentrations of chemicals in the water affect GAC performance. Different organic chemicals in the feedwater can compete for GAC adsorption "sites," which affects the number of BV between media replacements.

Table 5-1 Option 1A (GAC in Existing Filters) Calculation Basis

PARAMETER	UNITS	VALUE
Number of Existing Filters	Number	14
Area per Filter	ft^2	435
Dimensions, L x W x D (Depth of GAC media)	ft	15 x 29 x 15.58 (4)
Capacity Rating, each filter	mgd	2.5
Loading Rate, Capacity (Average Day) with All Filters	gpm/ft^2	4 (1.6)
Empty Bed Contact Time (EBCT), Capacity (Average Day) with All Filters	minutes	7.5 (18.7)
Number of New Staff	Number	1
Bed Volume (BV), assumed	Number	6,000 and 12,000
GAC Price	$/lb	1.25
One-Time Replacement of Non-GAC Media (sand and gravel)	$ (Lump Sum)	$660,000

An additional staff member has been included for Option 1A. While it is likely that additional operators would not be needed because the existing filters would be operated as they currently are, it is anticipated that additional staff time would be needed for maintaining the equipment since the frequency of change-outs could yield additional wear as well as a need for additional instrument calibration and staff time to coordinate GAC replacement activities.

The GAC price applied in these calculations is based on Black & Veatch experience and discussions with potential bidders. The price includes removal and replacement of the media with virgin GAC, disposal or regeneration of the spent media by the supplier, freight to and from the site, and field service personnel provided by the media supplier to remove the old media and install the new media. Therefore, for the development of the planning level scenario presented in this TM the price is based on essentially a turn-key arrangement with the GAC supplier providing a full range of services. If the project is subsequently implemented the GAC procurement method and supplier's scope could be optimized, such as to include more utility-provided labor component, regeneration and/or return of media, if that would yield a more cost-effective solution for CFPUA.

There would be no new facilities with this option, so there would be no new buildings and no construction costs. The initial cost incorporates the initial GAC media replacement as well as a budget for a one-time replacement of the sand and gravel in the existing filters. The reason for including an initial replacement of the sand and gravel would be to eliminate the possibility that PFAS compounds could have accumulated in that part of the media that could subsequently be released into the filtrate. Subsequent GAC replacement costs are included in the annual costs presented herein.

The annual operating costs and present worth of Option 1A is dependent on the replacement frequency of the GAC media. CFPUA is conducting testing to better quantify the replacement frequency given their water quality. On another project Black & Veatch has observed about 12,000 BV between GAC replacement events when applied to removing similar PFAS compounds, but not GenX, and at a TOC concentration that is lower than at the Sweeney WTP. The higher TOC concentration in the Cape Fear River could reduce the number of BV to less than 12,000 BV. To provide a sensitivity analysis both 6,000 BV and 12,000 BV scenarios are considered in this evaluation. At 12,000 BV with average flow conditions the GAC media would be replaced about every 5.2 months (156 days). At 6,000 BV the replacement would be twice as often, about every 78 days. At 12,000 BV and assuming 2 of 14 filters out of service for one week for each change-out, then filtration capacity would be reduced about one-third of the time (32 percent). At 6,000 BV it would be about two-thirds of the time. A capacity of up to 30 mgd could be provided with 12 of 14 filters in service based on the current design rate of 4 gpm/ft^2. If that limitation in available filtration area is unacceptable then standby filters could be added, which would add to the project's initial cost.

The planning level cost opinion for Option 1A is presented in Table 5-2.

Table 5-2 Option 1A (GAC in Existing Filters) Planning Level Cost Opinion

PARAMETER	OPTION 1A
Description	GAC in Existing Filters
Initial Cost, $ in millions	$1.7 million
Annual Operating Costs, $ in millions/yr	$3.0 million to $6.0 million
Present Worth (PW) of Annual Costs, $ in millions	$42 million to $82 million
Total Present Worth (TPW), $ in millions	$44 million to $84 million

6.0 Options 1B (GAC Contactors Located Downstream from Existing Filters) & 1C (Deep Bed Version of 1B)

The calculation basis for Options 1B (GAC Post-Filtration: Located Downstream from the Existing Filters) and 1C (Deep Bed Version of 1B) are presented in Table 6-1. Option 1C, a deeper bed version of 1B, was not considered in TM1, but has been incorporated into this memorandum (TM2). Having a deeper bed would add some cost but would also allow a longer time period between GAC replacement events, thereby causing less disruption to plant operations.

For this study, the same number of BV was applied to Options 1B and 1C as for 1A to facilitate comparison. Testing is being conducted to better quantify the BV values for the specific source water.

The main difference between Option 1A and Options 1B/1C is the location of the new GAC media. For Option 1A, the GAC media would be installed in the existing filter boxes. For Options 1B/1C, the new GAC media would be installed in new contactors that would be located downstream from the existing filters. In Option 1A, the new GAC would provide both filtration of the water (e.g., removing particles and turbidity) as well as to adsorb GenX and other organic materials from the water, while with Options 1B/1C, the GAC would be treating already filtered water and would only provide the adsorption mechanism. One aspect of the testing that is being conducted is to compare GAC adsorption when applied to settled water (like 1A) or filtered water (like 1B/1C).

The main design parameters were assumed to be the same for Options 1A, 1B, and 1C to facilitate comparison, although 1C has a longer EBCT. A difference between 1A and 1B/1C is that a transfer pump station is provided with Options 1B and 1C to transport the water from the existing header to the new treatment area and to provide the pressure needed to drive the water through the contactors, while 1A does not need a new pump station. In addition a new backwash pump has been included for Options 1B and 1C. During more detailed design tasks an optimization to consider would be dividing the 1B/1C contactors into cells to possibly allow use of the existing backwash pumping equipment.

Table 6-1 Option 1B (GAC Contactors Post-Filtration) and Option 1C (Deep Bed Version of 1B) Calculation Basis

PARAMETER	UNITS	OPTION 1B	OPTION 1C
Loading Rate, Capacity (Average Day) with All Filters	gpm/ft^2	4 (1.6)	4 (1.6)
Empty Bed Contact Time (EBCT), Capacity (Average Day) with All Filters	Minutes	7.5 (18.7)	20 (50)
Number of New Staff	Number	2	2
Bed Volume (BV), assumed	Number	6,000 and 12,000	6,000 and 12,000
GAC Price	$/lb	1.25	1.25

Two additional staff members have been included in the annual costs for Options 1B and 1C to account for an addition to the WTP that would require more labor support than Option 1A.

The planning level cost opinion for Options 1B and 1C are presented in Table 6-2.

Table 6-2 Option 1B (GAC Contactors Post-Filtration) and Option 1C (Deep Bed Version of 1B) Planning Level Cost Opinions

PARAMETER	OPTION 1B	OPTION 1C
Description	GAC Contactors Post-Filtration	Deep Bed Version of 1B
Initial Cost, $ in millions	$28 million	$32 million
Annual Operating Costs, $ in millions/yr	$3.3 million to $6.3 million	$3.4 million to $6.4 million
Present Worth (PW) of Annual Costs, $ in millions	$45 million to $86 million	$46 million to $86 million
Total Present Worth (TPW), $ in millions	$73 million to $114 million	$78 million to $118 million

As with Option 1A, the operating costs and present worth values for Options 1B and 1C are also dependent on the replacement frequency of the GAC media. Therefore, as with Option 1A both 6,000 BV and 12,000 BV scenarios are considered in this evaluation. The GAC replacement frequency would be as discussed in the previous section, about every 78 days or 156 days, respectively.

Options 1B and 1C would require space for a new transfer pump station as well as a new GAC contactor building. The transfer pump station area would be about 500 ft^2 and the GAC contactor building would be about 11,000 ft^2. The cost for buildings has been included in the cost opinion presented in this memorandum. A concept of the location of Options 1B or 1C is presented on Figure 6-1.

As indicated in the figure, the new contactors would likely infringe on the stormwater detention pond that captures runoff and allows a degree of settlement before discharging off site. This issue would need to be addressed with regulators. Any costs associated with alternative or additional treatment of stormwater have not been included.

SITE PLAN

1" = 100'-0"

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

PW:
PW FILE:
SAVED:STO49530, 8/23/2017 8:54:42 AM
PLOTTED:STO49530, 8/23/2017 9:04:08 AM
USER:STO49530
DWG VER:
XREF1:
XREF2:
XREF3:
XREF4:

BLACK & VEATCH
Building a world of difference.
Black & Veatch Corporation
Kansas City, Missouri

CAPE FEAR PUBLIC UTILITY AUTHORITY
SWEENEY WATER TREATMENT PLAN

OPTION 1B - GAC CONTRACTORS
SITE PLAN

DESIGNED:
DETAILED:
CHECKED:
APPROVED:
DATE:

0 1/2 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO FULL SCALE

PROJECT NO.

FIGURE 6-1
SHEET
OF

FD7000
D7000

7.0 Option 3 (RO/NF Located Downstream from Existing Filters)

The calculation basis for Option 3 (RO/NF Post-Filtration: Located Downstream from the Existing Filters) is presented in Table 7-1.

Table 7-1 Option 3 (RO/NF Post-Filtration) Calculation Basis

PARAMETER	UNITS	VALUE
Design Flows: RO/NF Feed Permeate Concentrate	mgd (gpm)	41.2 (28,600) 35 (24,300) 6.2 (4,300)
Average Flows: RO/NF Feed Permeate Concentrate	mgd (gpm)	16.5 (11,400) 14 (9,700) 2.5 (1,700)
Recovery	percent	85
Flux	gfd	10.4
Cartridge Filter Element Replacement Rate	per year	6
RO/NF Element Replacement Rate	per year	1/7 = 14.3 percent (i.e., 7 year service life)
Value of Additional Prefiltered Water	$/1000 gal	0.5
Allocation for Land Acquisition (Only used for Option 3)	$	$400,000
Number of New Staff	Number	5

To provide a basis for determining a planning level cost opinion, the flows listed in Table 7-1 were assumed, which incorporated the assumption that all of the finished water would be comprised of RO/NF permeate. A review of the scientific literature (refer to TM1, Black & Veatch, 2017) indicates that RO/NF has generally provided about 95 percent rejection of similar PFAS compounds, although in some studies rejections of about 70 percent to 99 percent have been observed. In some cases rejection was influenced by pH, which indicates the mechanism may be more complex than just size exclusion. As an example, if a source water concentration would be 631 ng/L (which is the average concentration of GenX observed by Sun et al. 2016), 95 percent rejection would result in a concentration of 31 ng/L in the permeate. While the concentrations in the Cape Fear River are not well understood, and even thought the July 2017 measurements by NCDEQ resulted in all GenX concentrations being below 140 ng/L, it appears logical at this point to plan to treat 100 percent of the finished water flow for the RO/NF option. To further illustrate this, even if the feedwater concentration would be 140 ng/L at 95 percent rejection the concentration in the permeate would be 7 ng/L. If instead of 100 percent treatment a small (5 percent) bypass flow were allowed with a feed concentration of 140 ng/L and 95 percent rejection, the finished water concentration would roughly double to 14 ng/L. Therefore, for this level of study it appears reasonable to assume full RO/NF treatment to account for unknowns, including the concentration in the river, the actual rejection, and the finished water goals. If NF/RO is selected for full-scale implementation, a further study to determine the impact of a by-pass stream on cost, water quality, and operations would be warranted.

As discussed in the previous paragraph, a review of the scientific literature indicated that RO/NF has generally provided about 95 percent rejection of similar PFAS compounds, although in some studies rejections of about 70 percent to 99 percent have been observed. Some of the studies indicated that NF provided rejection values as high as RO while others indicated that rejection by the NF membrane considered in those studies was lower than for RO. In general, NF and RO systems are very similar and have the same types of components and ancillary support equipment. In the past, RO operated at higher pressures than NF and, therefore, exhibited higher energy use, but advancements in membrane technology have significantly reduced the operating pressure difference. Membrane selection could be determined during a more detailed design phase and could be based on site-specific testing. At the current level of planning and development of a cost opinion, this evaluation is based on the use of either NF or low pressure RO.

Unlike the GAC options (1A, 1B, and 1C), Option 3 (RO/NF) would require an increase in feedwater flow rate (thereby consuming more raw water) and would also yield an increase in wastewater flow rate (because of the concentrate stream). A related RO/NF parameter is recovery, the ratio of permeate flow to feed flow. Generally recovery is set as high as possible to minimize flow rates of the feed and concentrate streams. During detailed design recovery would be determined on the basis of concentrations in the feedwater of what are called sparingly soluble salts. The goal is to have as high a recovery as possible without causing sparingly soluble salts to precipitate in the membrane system, resulting in more frequent chemical cleanings, higher operating costs, shorter membrane service life, and capacity shortfalls. The conductivity of the Cape Fear River water (less than 200 μS/cm) indicates that this is relatively low concentration water. Many RO/NF facilities achieve 85 percent recovery, so it appears reasonable to base the current level of planning and development of a cost opinion on that value (while also including antiscalant chemical addition to the feedwater). The recovery value and other design conditions would be evaluated in more detail during a detailed design phase.

Related to the concept of recovery, the RO/NF option would result in increases in both raw water consumption and wastewater flow rate. Design and average flow rates are listed in Table 7-1. In some situations, especially for inland RO/NF facilities, disposal of the concentrate can be a major cost item. For this evaluation it was assumed that the concentrate could be disposed of via a nearby existing river outfall. It was also assumed that the portion of the capital cost that was calculated by the cost model to cover yard piping expenses (which was more than $4 million in capital expenses plus the added factors for contractor/ subcontractor mark-ups and non-construction costs, including contingency) would provide sufficient budget to include the relatively short discharge line. However, there is risk associated with this assumption. The regulatory agency might not approve of the concentrate discharge, and other methods of handling and disposal could add significant cost to the RO/NF option. If the RO/NF option receives additional consideration, it is recommended that discussions be held with the regulator early-on in project development.

In addition to generating a concentrate flow, the RO/NF option consumes more feed flow than the GAC options. The capital cost opinion for the RO/NF option accounts for this by including additional filters. The operating cost opinion accounts for this by including a value for the incremental processing costs for additional filtered water at average flows, applying the basis listed in Table 7-1; however, no value is assigned to the raw water itself.

Another difference between RO/NF and the other options is that RO/NF would require additional post-treatment of the finished water before sending it to the distribution system. Costs for this have been included in this study. The reason for the additional post-treatment is that RO/NF product water is somewhat corrosive due to the lower pH, alkalinity, and hardness as well as other factors such as differences in the sulfate/chloride concentration ratio. The RO/NF product water needs some post-treatment to make it compatible with the existing distribution system. If the RO/NF option is selected, it is recommended that additional development of the post-treated water conditions be conducted.

A key parameter for RO/NF design and operations is flux, which is the RO/NF equivalent to hydraulic loading rate. With GAC filters (and other granular media filters) hydraulic loading rate is the filtered water flow rate per unit of cross-sectional flow area and is generally expressed in gpm/ft^2. Flux is the flow rate of permeate per unit of membrane area and is generally expressed in gallons per ft^2 per day (gfd). The higher the flux, the lower the capital cost because higher flux means fewer membrane elements and pressure vessels are purchased. Flux is selected on the basis of past experience treating similar water and, if possible, verified by site-specific testing. If the flux is set too high, the membrane system will have problems with "fouling," resulting in more frequent chemical cleanings, higher operating costs, shorter membrane service life, and capacity shortfalls. For this evaluation a conservative flux was selected because the feed water is from a surface source, which tends to yield more fouling than treating groundwater. It is generally easier to control fouling to manageable levels at the flux selected for this evaluation.

RO/NF is typically described as being an energy intensive process because it consumes more electrical energy than many other water treatment processes. However, modern RO/NF facilities consume less electricity than in the past. Cost of the average energy consumption was included in the annual costs that were determined for this evaluation. Regarding capital costs, preliminary calculations indicate that the RO/NF option could add about 4.5 MW in connected electrical power at the WTP. Preliminary discussions with the energy provider, Duke Energy, indicate that some new infrastructure would be needed to provide that additional amount of electricity. Duke Energy indicated that they would provide some portion of the new infrastructure since this development would provide them with a new major consumer of electricity. For this evaluation it was assumed that the portion of the capital cost that was calculated by the cost model to cover on-site electrical infrastructure (which was more than $4 million plus added costs because of factors for contractor/subcontractor mark-ups and non-construction costs, including contingency) would provide sufficient capital cost budget for this service.

The evaluation indicates that the main RO/NF building would not fit on the existing site of the Sweeney WTP. An allocation has been included in Table 7-1 and in the calculation of the cost opinion to allow for the possible purchase of additional land area. This is essentially a placeholder value and the actual cost of land acquisition is unknown. If the RO/NF option is to receive additional consideration, more detail is recommended to better understand the land costs.

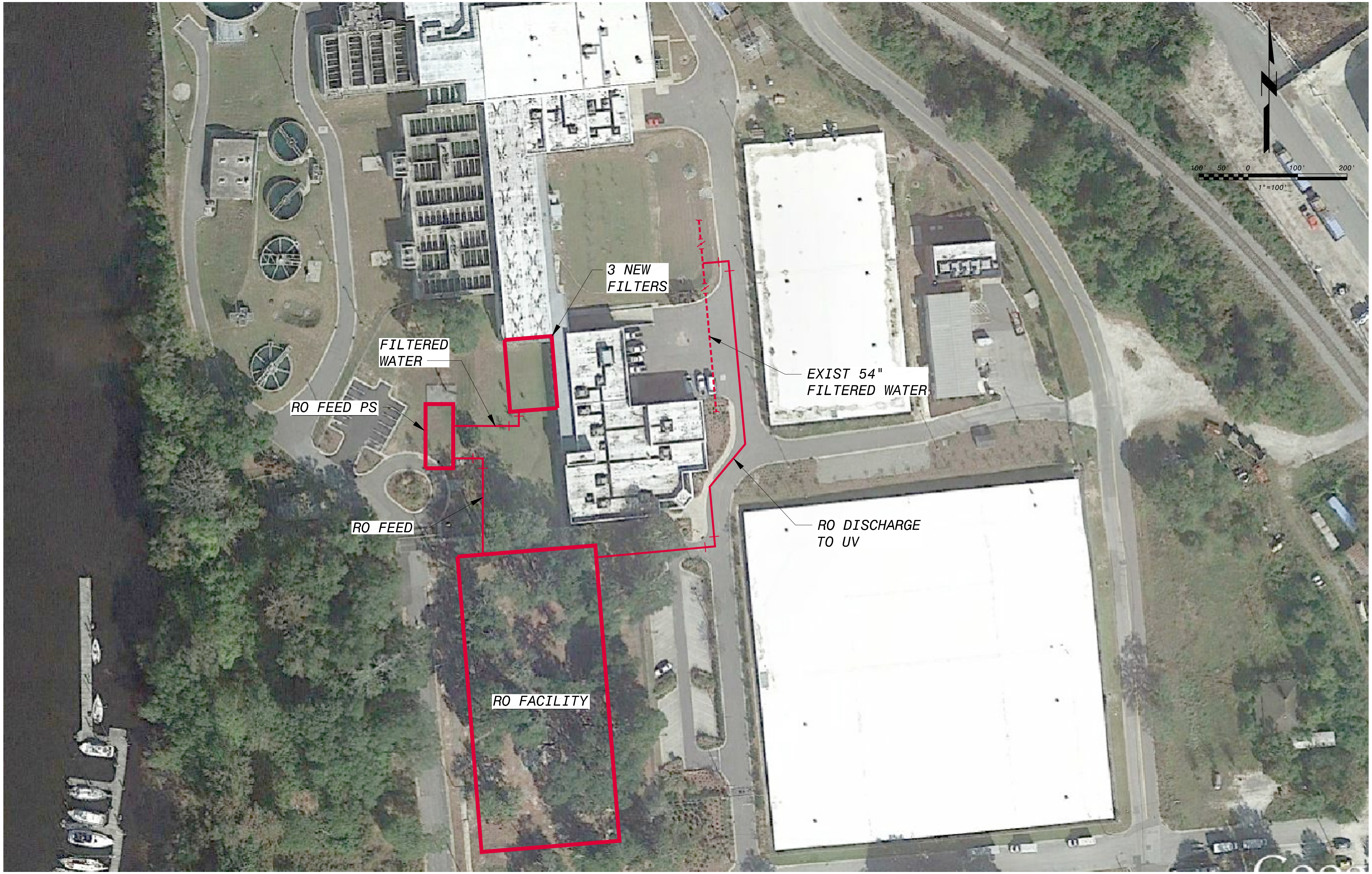
Five new staff members were included for Option 3 (RO/NF) to account for this addition to the WTP, since RO/NF would require more labor support than Options 1A (GAC in Existing Filters) and 1B (GAC Post-Filtration).

Option 3 would require space for an addition to the existing filtration area, a new transfer pump station, and a new building for the RO/NF and related ancillary equipment. The new filter area could be located outside with sunshades, like the existing filters. The additional area for the filtration step would be about 2,300 ft^2, the pump station would be about 500 ft^2, and the RO/NF building would be about 40,000 ft^2. Part of the RO/NF building area could be located with the transfer pump station building as needed to fit on the site. The costs for the shade-covered area and building(s) have been included in the cost opinion presented in this memorandum. A concept of Option 3 is shown in Figure 7-1. The area identified for the RO/NF Facility is in the park to the south of the existing Sweeney WTP site.

The planning level cost opinion for Option 3 (RO/NF) is presented in Table 7-2.

Table 7-2 Option 3 (RO/NF Post-Filtration) Planning Level Cost Opinion

PARAMETER	OPTION 3
Description	RO/NF Post-Filtration
Initial Cost, $ in millions	$113 million
Annual Operating Costs, $ in millions/yr	$3.3 million
Present Worth (PW) of Annual Costs, $ in millions	$45 million
Total Present Worth (TPW), $ in millions	$158 million



SITE PLAN

1" = 100'-0"

NO. | BY | CK | APP
DATE | REVISIONS AND RECORD OF ISSUE

PW:
PW FILE:
SAVED:ST049530, 8/23/2017 8:53:12 AM
PLOTTED:ST049530, 8/23/2017 10:14:52 AM
USER:ST049530
XREF1:
XREF2:
XREF3:
XREF4:
DWG VER:

BLACK & VEATCH
Building a world of difference
Black & Veatch Corporation
Kansas City, Missouri

CAPE FEAR PUBLIC UTILITY AUTHORITY
SWEENEY WATER TREATMENT PLAN

OPTION 3
SITE PLAN

DESIGNED:
DETAILED:
CHECKED:
APPROVED:
DATE:

0 1/2 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO FULL SCALE

PROJECT NO.

FIGURE 7-1
SHEET
OF

FD7000
D7000

8.0 Discussion

The planning level cost opinions for the options evaluated in this memorandum are summarized in Table 8-1.

Table 8-1 Summary of Planning Level Cost Opinions

PARAMETER	OPTION 1A	OPTION 1B	OPTION 1C	OPTION 3
Description	GAC in Existing Filters	GAC Contactors Post-Filtration	Deep Bed Version of 1B	RO/NF Post-Filtration
Initial Cost, $ in millions	$1.7 million	$28 million	$32 million	$113 million
Annual Operating Costs, $ in millions/yr	$3.0 million to $6.0 million	$3.3 million to $6.3 million	$3.4 million to $6.4 million	$3.3 million
Present Worth (PW) of Annual Costs, $ in millions	$42 million to $82 million	$45 million to $86 million	$46 million to $86 million	$45 million
Total Present Worth (TPW), $ in millions	$44 million to $84 million	$73 million to $114 million	$78 million to $118 million	$158 million

Notes: GAC = Granular Activated Carbon; RO/NF = Reverse Osmosis/Nanofiltration

Option 1C was added after TM1 was written. Option 1C is a deeper bed version of Option 1B.

Option 1A's initial cost includes an initial load of GAC media and one-time replacement of sand and gravel. The GAC options (1A, 1B, 1C) would have higher initial costs if standby filters/contactors were added to provide full capacity when units are off-line during GAC replacement events.

Annual costs for the GAC options (1A, 1B, 1C) are a function of media life. The cost ranges in the table are based on 6,000 and 12,000 bed volumes (BV). A 6,000 BV case would need to change GAC twice as often as a 12,000 BV case. CFPUA is conducting testing to determine BV at Cape Fear River concentrations.

In accordance with recommendations in TM1, a detailed cost opinion was not prepared for Option 2, Ion Exchange (IX); however, it is the engineer's opinion that TPW for Option 2 would be roughly in line with Option 1B. IX is less widely practiced for organic contaminant removal than GAC or RO/NF. However, recent pilot testing elsewhere of IX resins has shown promise as a treatment technology for removal of perfluorinated compounds from drinking water. Therefore, as a contingency CFPUA is conducting IX testing.

As anticipated at the outset of this study, Option 1A has the lowest TPW, Option 3 the highest, and 1B/1C are between them. Option 1C, the deep bed version of 1B, has a higher cost by $4 million (a 14 percent increase in initial cost). The deeper beds would result in higher construction costs and more GAC media would need to be purchased for the initial loading. Operating costs for those options are almost the same, since the GAC consumption rate is the same while the feed water pumping costs would be slightly high to service the deeper contactors.

Because the costs for the GAC options (1A, 1B, and 1C) are directly dependent on the frequency of GAC replacement, a sensitivity analysis was conducted on those options. If the GAC bed life were reduced from an assumed value of 12,000 BV to only 6,000 BV, the GAC would need to be replaced twice as often. For example, at 12,000 BV the time period between GAC media replacement events is about every 5.2 months (156 days) at average flow conditions with all of the filters/contactors being operated in parallel. If the BV value is reduced by 50 percent to 6,000 BV, the time period between replacement events would be cut in half, to about every 78 days and the annual operating costs would roughly double.

In addition to considering the costs, it is useful to consider non-financial factors when comparing these options. Related issues are summarized as follows.

- Option 1A (New GAC in Existing Filters). This is the lowest cost option due to the comparatively low initial cost. Currently the GAC media in the existing filters provides filtration, while if new GAC were installed it would provide both filtration and adsorption to remove dissolved organic materials. A key issue with all of the GAC options (1A, 1B, and 1C), is the change-out frequency. Testing is being conducted to verify preliminary assumptions. At the 6,000 BV to 12,000 BV cases considered herein, change-out would be every 78 days to 156 days for each unit. Such frequent servicing would reduce plant capacity, unless standby filters are added and could be an impediment to operations. Other aspects of GAC options (1A, 1B, and 1C) that can also be tested include a risk of chromatographic peaking (which could result in higher concentrations in the effluent than in the influent) and a benefit of removing other compounds such as Contaminants of Emerging Concern (CEC) or Pharmaceuticals and Personal Care Products (PPCP).

- Option 1B (GAC Contactors Post-Filtration). This option has the same advantages and limitations of Option 1A, since they both apply GAC; however, 1B has the added feature of locating the new process downstream from the filters. Therefore, while the frequency of GAC change-outs could be an impediment to the operations staff, GAC replacement events would not directly impact filtration activities. The GAC in Option 1B would remove organic materials via adsorption, but it would not also provide filtration; that would continue to be accomplished by the existing filters. As with Option 1A, 1B (and 1C) would provide the benefit of removing other CEC and PPCP compounds. If adsorption were not needed in the future, the change-out frequency of 1A could be reduced or mostly eliminated and Options 1B or 1C could be converted to use as filters, such as for a plant expansion.

- Option 1C (Deep Bed Version of 1B). Option 1C, a deep bed version of Option 1B, was included to consider the cost impact of contactors with a longer time period between breakthrough and therefore a longer time between GAC replacement events. Due to increased construction costs and a greater amount of GAC media initially installed, the capital costs of 1C would be higher than with 1B; however, the operating costs would be essentially the same, since the consumption of GAC would be the same. Having longer time periods between GAC replacement events would be less disruptive to plant operations.

- Option 2 (IX Post-Filtration). There are similarities between Option 2 (IX) and the post-filtration GAC options (1B and 1C), including operating costs affected by the number of BV and the associated frequency of media replacement. Testing is being conducted to allow comparison of the number of BV for GAC and IX media and better quantification of costs.

- Option 3 (RO/NF Post-Filtration). Option 3 has the highest costs, both initial and total present worth, as well as requiring the greatest amount of land. The evaluation indicates that the main RO/NF building would not fit on the existing Sweeney WTP site. An alternative location to consider would be the park area to the south adding to the complexity of the project. It is unknown if that land would be available for this purpose. In addition, Option 3 includes the drawbacks of consuming the greatest amount of raw water, disposal of the concentrate stream and post-treatment to control corrosion. The additional raw water consumption could limit future plant expansion options and the concentrate disposal could increase the projected cost opinion, depending on the requirements of the regulatory agency. The costs for a concentrate disposal method have been included in the evaluation, but it is unknown at this time if the regulatory agency will accept this method.

9.0 Summary/Recommendations

1. This memorandum presents on planning-level cost opinions for treatment methods to remove organic chemicals known as perfluoroalkyl substances (PFASs), including a type called GenX.

2. As expected, Option 1A is the lowest cost option and Option 3 is the highest cost (refer to Tables ES-1 and 8-1). The initial costs are $1.7 million for Option 1A, $28 million for Option 1B, $32 million for Option 1C (a deep bed version of 1B), and $113 million for Option 3. The Total Present Worth values for these options are $44 million to $84 million, $73 million to $114 million, $78 million to $118 million, and $158 million, respectively.

3. A detailed cost opinion was not prepared for Option 2 (IX) in accordance with the recommendations in TM1; however, it is the engineer's opinion that Total Present Worth for Option 2 would be roughly in line with Option 1B.

4. The annual operating costs and the Total Present Worth of the GAC and IX options are sensitive to the frequency of media replacement. For example, doubling the GAC replacement frequency from about every 5 months to about every 2.5 months would roughly double the Present Worth of 1A and increase 1B and 1C by about 60 percent. Testing is being conducted to refine the understanding of this variable.

5. Frequent replacement of the media (GAC or IX) not only adds to the operating costs, frequent replacement could also be an impediment to operations of the WTP.

6. In addition, non-financial aspects that could influence consideration of GAC and IX include selectivity and chromatographic peaking. Regarding chromatographic peaking, this can result in higher concentrations in the effluent than in the influent for some compounds. Ongoing testing will help refine the understanding of these variables.

7. Limitations for Option 3 (RO/NF) include the need for additional land area, the size of a new process building, consumption of a larger amount of raw water, and the requirement to dispose of concentrated wastewater. It is currently unknown if it would be possible to acquire the additional land. It is also unknown if the regulatory agency would allow the concentrate disposal method that have been included kin the cost model. Increasing the raw water consumption rate could limit future plant expansion options.

10.0 List of Abbreviations

AACE	Association for the Advancement of Cost Engineering
BV	Bed Volume
CEC	Contaminants of Emerging Concern
EBCT	Empty Bed Contact Time
EPA	United States Environmental Protection Agency
ft^2	Square Foot
GAC	Granular Activated Carbon
gfd	gallons per ft^2 per day = gpd/ft^2
gpm	gallon per Minute
IX	Ion Exchange
MCL	Maximum Contaminant Level
mgd	million gallons per Day
NCDEQ	North Carolina Department of Environmental Quality
NF	Nanofiltration
ng/L	nanogram per Liter
PFAS	Perfluoroalkyl Substance
PFC	Perfluorinated Compound
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulfonate
PFPrOPrA	Perfluoro-2-Propoxypropanoic Acid (aka GenX)
PPCP	Pharmaceuticals and Personal Care Products
PW	Present Worth
RO	Reverse Osmosis
TM1	Technical Memorandum 1
TM2	Technical Memorandum 2
TPW	Total Present Worth
UV	Ultraviolet
WTP	Water Treatment Plant
Yr	Year

11.0 References

Black & Veatch (2017). Technical Memorandum 1 Desktop Evaluation of Alternatives – GenX and Other PFAS Treatment Options Study, Project 196369, prepared for Cape Fear Public Utility Authority (CFPUA), July, 2017.

Black & Veatch Project 145726, Process Design Memorandum for Sweeney WTP Expansion, February 16, 2007.

Black & Veatch Project 145726, Civil Design Memorandum for Sweeney WTP Expansion, May 22, 2007.

CFPUA (2017). CFPUA Receives New GenX Results, Posted on Sept 13, 2017. (http://www.cfpua.org/CivicAlerts.aspx?AID=741)

Dickenson, Eric R. V., and Christopher Higgins (2016). Treatment Mitigation Strategies for Poly- and Perfluoroalkyl Substances, WEF Project 4322, ISBN 978-1-60573-234-3, Water Research Foundation, Denver, Colorado.

EPA (2016). Fact Sheet PFOA and PFOS Drinking Water Health Advisories, EPA 800-F-16-003, November 2016.

NCDEQ (2017a). NCDEQ confirmed that Chemours had stopped discharging GenX wastewater (https://deq.nc.gov/deq-verifies-chemours-has-stopped-discharging-genx-wastewater).

NCDEQ (2017b). GenX Sampling Sites (https://deq.nc.gov/news/hot-topics/genx-investigation/genx-sampling-sites).

Sun, M., Arevalo, E., Strynar, M., Lindstrom, A., Richardson, M., Kearns, B., Pickett, A., Smith, C., and Knappe, Detlef R. U. (2016). Legacy and Emerging Perfluoroalkyl Substances are Important Drinking Water Contaminants in the Cape Fear River Watershed of North Carolina, Environmental Science & Technology Letters 3(12): 415-419, American Chemical Society, November 10, 2016.

Water Research Foundation (WRF) (2016). Poly- and Perfluoroalkyl Substances: Background Technical Information, 5 pp., WRF, Denver, Colorado, August 2016.

FINAL

PROGRESS UPDATE

Emerging Contaminants Treatment Strategy Pilot Study

B&V PROJECT NO. 196369

NORTH CAROLINA
PROFESSIONAL
SEAL
8749
ENGINEER
H. KEITH PROFFIT

11/01/17

PREPARED FOR

Cape Fear Public Utility Authority

1 NOVEMBER 2017

BLACK & VEATCH

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1.0 Purpose

This document presents the status of ongoing bench- and pilot-scale testing to evaluate the performance of several proposed treatment technologies in their removal of perfluoroalkyl substances (PFASs), including perfluoro-2-propoxypropanoic acid (commonly known as GenX).

2.0 Introduction

PFASs have been detected in the Cape Fear River, which is the source of raw water for the Sweeney Water Treatment Plant (WTP). The Sweeney WTP provides drinking water to Cape Fear Public Utility Authority (CFPUA) customers in the City of Wilmington and New Hanover County in North Carolina.

In response to the detection of GenX and other PFASs in the Cape Fear River and because of concern over potential health effects, CFPUA is proactively investigating the feasibility and effectiveness of PFAS removal technologies. CFPUA is one of the first utilities in the United States to pursue treatment to target removal of these compounds. Initial evaluations performed by Black & Veatch were provided in Technical Memoranda 1 and 2. As a result of those evaluations, bench- and pilot-scale testing of granular activated carbon (GAC) filter media and ion exchange (IX) resins was initiated. The details of the bench- and pilot- scale testing are presented herein.

3.0 Testing and Analysis

Granular activated carbon filter media and ion exchange resin were selected for bench- and pilot-scale testing. Reverse osmosis/nanofiltration was excluded because of much higher life-cycle cost and potential challenges related to disposal of the concentrate, but the technology will be considered if testing of GAC and IX fail to meet testing goals. The following sections provide information on the testing.

3.1 TESTING GOALS

The primary goal of the testing is to establish the adsorption characteristics for PFASs and other contaminants of emerging concern (CECs) on GAC media and IX resin. These characteristics will be used to refine the previous study-related evaluations and identify the most advantageous short- and longer-term treatment strategies for removal of PFASs and CECs at the Sweeney WTP. The data will help define a design basis for full-scale implementation of the selected technology. Ancillary benefits are also being identified as part of the study, such as reductions in total organic carbon (TOC), disinfection byproduct (DBP) formation, and inorganic compounds.

3.2 MEANS AND METHODS

Pilot testing is used to determine the adsorption characteristics of PFASs on GAC media and IX resins. Accelerated column testing was performed on two GAC media as one month of operating results can be used to estimate up to one year of performance. The same accelerated testing is not available for IX resins. Each test is discussed in the following sections.

During the initial screening process, commercially available GAC media and IX resins were surveyed to identify products that have the highest likelihood of achieving PFAS removal for testing. Testing of surveyed media and resins was then prioritized based on experience and suitability with PFAS removal.

3.2.1 Accelerated Column Test

The accelerated column test is designed to simulate year-long operation of a full-scale bed of GAC using a smaller bench-scale column that is operated for around a month. The test consists of scaling down commercial GAC by pulverizing it into smaller particles to achieve a proportionate adsorption capacity and placing it in a scaled-down column. Empty bed contact time (EBCT) for the accelerated column test is maintained equivalent to the full-scale design. A sample of water from the plant is pumped through the column for several weeks. Samples are collected for analytical testing to establish a breakthrough curve for the GAC media. A flow diagram of the ACT rig is shown in Figure 3-1 and an image of the test rig in Figure 3-2.

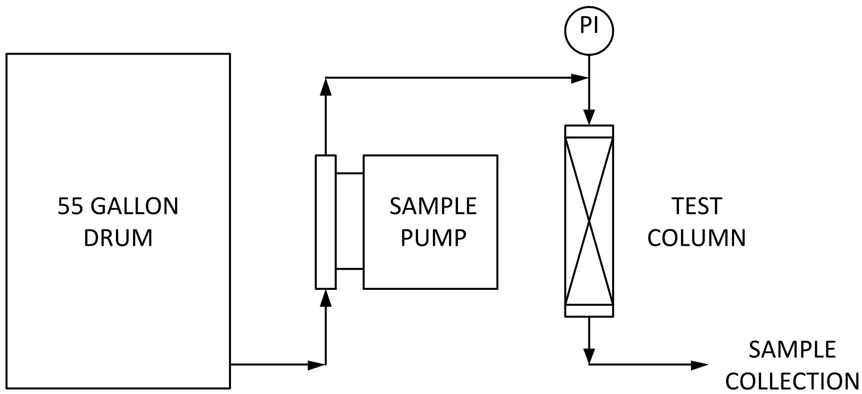

Figure 3-1 Accelerated Column Test Flow Diagram

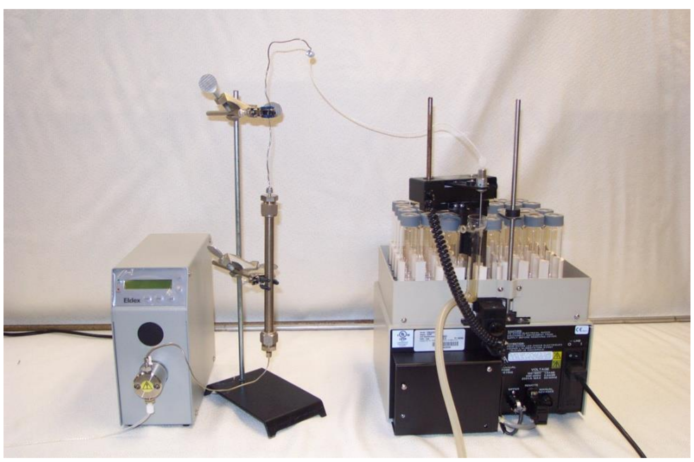

Figure 3-2 Accelerated Column Test Equipment

The ACT test for CFPUA was performed by Calgon Carbon Corporation, a supplier of granular activated carbon. Two 55 gallon drums of water drawn downstream from the existing filters at the Sweeney WTP were submitted for testing. Two ACTs were performed, one using Calgon's Filtasorb 400, and the other using Filtrasorb 600. Both GAC products were scaled down from mesh sizes of 12 by 40 for the test. Both tests were run simultaneously in parallel for 27 days to simulate one year of full-scale operation. Each test was run using an EBCT of 10 minutes.

3.2.2 Pilot Test

Pilot testing is used to evaluate performance of a design on a small scale in real-time prior to investment in full-scale implementation. The CFPUA pilot operates in parallel with the existing treatment scheme at the Sweeney WTP. The pilot consists of six test columns: four columns containing GAC media and two columns containing IX resin. A very small portion of the process flow in the WTP is diverted to each of the columns to assess placement within the overall process scheme and performance. A process flow diagram of the pilot is presented in Figure 3-3 and a picture of the GAC columns is illustrated in Figure 3-4.

Each column is equipped with valves and a flow meter to regulate flow through the column. Samples are collected at the inlet and outlet of the columns for analytical testing to measure adsorbent performance. Samples are collected at the following locations:

- Plant influent
- Existing filter influent
- Existing filter effluent
- Plant effluent prior to distribution
- Outlet of each test column

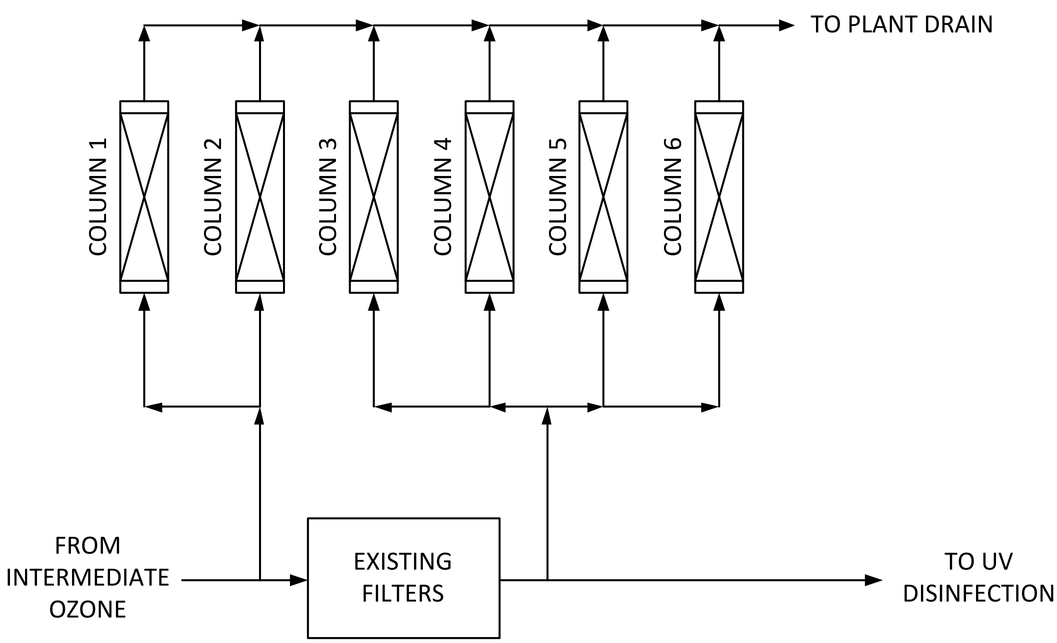

Figure 3-3 Pilot Test Flow Diagram

Figure 3-4 Pilot Test Skid

Operation of columns 1 through 4 began on August 2, 2017 and columns 5 and 6 (not shown) began operation on September 5, 2017. Each column containing GAC was run at an EBCT of 10 minutes. Each column containing IX resin was run at an EBCT of 1.5 minutes. The adsorbent selected for each test column is listed in Table 3-1. All test columns have operated continuously since their start.

Table 3-1 Adsorbents

Column	Type	Adsorbent	Supplier
Column 1	GAC	GAC 1 (Filtrasorb F400 12x40)	Calgon
Column 2	GAC	GAC 2 (Filtrasorb F300 12x30)	Calgon
Column 3	GAC	GAC 3 (Filtrasorb F400 12x40)	Calgon
Column 4	GAC	GAC 4 (AquaCarb 1230 CX)	Evoqua
Column 5	IX	IX 1 (DOWEX PSR-2)	Evoqua
Column 6	IX	IX 2 (CalRes 2304)	Calgon

3.3 GAC INTERIM RESULTS TO DATE

Granular activated carbon is used in the accelerated column testing and the pilot testing. Preliminary ACT results included a discrepancy in the dilution factors used and the laboratory is repeating the analysis. No ACT test results are available at this time.

Interim results of the ongoing pilot testing are presented in Table 3-2. All data is reported based on equivalent bed volumes of water treated.

Each GAC test column is exhibiting gradual breakthrough of TOC and PFASs, led by GenX. Columns 1 and 2, which are being tested using water from upstream of the existing filters, are showing slower breakthrough for all PFASs than columns 3 and 4, which are being tested using water from downstream of the existing filters. Testing data show higher values for each PFAS analyte in the water post filter than in the water pre filter. This may indicate that chromatographic peaking is occurring in the existing filters, where the existing media is desorbing PFASs to preferentially adsorb another compound leading to higher concentrations of PFASs in the post filter water.

Also included in Table 3-2 are other emerging contaminants that include Endocrine Disrupting Compounds (EDCs) and Pharmaceutical and Personal Care Products (PPCPs). The four GAC columns are highly effective for the removal of these compounds at this point whereas IX is ineffective for the removal of those compounds.

Table 3-2 Sampling Results as of October 3, 2017

Pilot Supply		**Intermediate Ozone**		**Biologically Active Filter Effluent**			
	Column Influent	**GAC-1**	**GAC-2**	**GAC-3**	**GAC-4**	**IX-1**	**IX-2**
Bed Volumes	---	8,800	9,200	8,800	9,100	27,400	27,400
PFASs							
	ng/L	**Percent Breakthrough**					
GenX	24 -42.2	68	90	100	113	0	0
PFHxA	18-41	50	63	74	80	0	0
PFHpA	11-28	36	44	62	62	0	0
PFOA	9.8-17	22	28	47	43	0	0
PFBS	4-6.4	3	26	45	58	0	0
PFHxS	5.4-11	0	9	28	27	0	0
PFOS	9.4-24	0	0	18	15	0	0
Endocrine Disrupting Compounds (EDCs)/Pharmaceutical and Personal Care Products (PPCPs) (Percent Breakthrough)							
	μg/L	**Percent Breakthrough**					
Sucralose	0.864-0.928	14	14	25	15	96	94
Tris(chloropropyl) phosphate	0.06-0.07	0	0	0	0	100	114
Cotinine	0.003	0	0	0	0	100	100
Acesulfame-K	0.02-0.04	0	0	0	0	0	0

3.4 IX INTERIM RESULTS TO DATE

Ion exchange is only undergoing pilot testing. Interim results of the ongoing pilot testing are presented in Table 3-2. Neither ion exchange test column has – to date – exhibited any breakthrough of PFASs through approximately 27,400 bed volumes treated. This indicates that both IX columns are adsorbing PFASs such that their levels in the treated water are not detectable.

4.0 Discussion

- The bench-scale and pilot testing is ongoing and scheduled to continue through the first quarter of 2018 until testing goals are achieved.
- PFAS are being observed in the pilot GAC media effluent.
    - Columns 3 and 4 are very near or above the influent concentration for GenX.
    - Other PFAS continue to be partially removed.
- Ion exchange adsorbents have yet to show any breakthrough of PFASs.
- GAC columns are more effectively removing EDCs and PPCPs than IX columns.
- Testing will evolve as data is received to refine short- and long-term treatment strategies. This includes the replacement of adsorbents that fail to perform.
    - GAC 1 – Continue piloting until regulatory review of alternative filter media configuration is complete. Also awaiting complete breakthrough of PFAS, EDCs, and PPCPs.
    - GAC 2 – Continue piloting until regulatory review of alternative filter media configuration is complete. Also awaiting complete breakthrough of PFAS, EDCs, and PPCPs.
    - GAC 3 – Continue piloting to observe complete breakthrough of PFAS in a post filtration location.
    - GAC 4 – Continue piloting to observe complete breakthrough of PFAS in a post filtration location. Maintain the opportunity to include an alternative supplier.
    - IX 1 – Continue piloting to observe breakthrough of PFAS.
    - IX 2 - Continue piloting to observe breakthrough of PFAS.
- Additional pilot columns are being considered for testing of other GAC and IX adsorbents.

5.0 Conclusions/Recommendations

The following conclusions and recommendations can be developed based on the interim testing results.

- PFAS are being detected in the pilot GAC media effluent after 1,600 bed volumes.
- EDCs and PPCPs are effectively removed by all GAC columns after 8,800 bed volumes.
- No PFAS have been observed in the IX column effluent after 27,400 bed volumes.
- EDCs and PPCPs are not effectively removed by either IX column.
- No cost evaluation has been completed comparing IX and GAC.

- No life-cycle costs have been developed comparing IX and GAC so it is premature to eliminate a technology at this time. Life-cycle cost development is occurring in parallel with the pilot study.

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Cape Fear Public Utility Authority

Project update for the period covering September 1 – 30th, 2017

Summary:

We are progressing along with the analysis and are on schedule. The first month has involved finding vendors for standards and supplies for the per-and poly-fluorinated compounds (PFAS) analysis. The standards ordered and received so far are listed in figure 1. The standards are a combination of internal standards that are enriched with carbon-13 and authentic standards. As the research progresses more standards will be ordered for structural confirmation as well as QA/QC purposes. All reagent and consumables have been ordered and received for the solid phase isolation and pre-concentration of PFAS from water. Method validation is currently underway using published quality assurance and quality control protocols. The figures of merit that need to be addressed include recoveries, blanks and precision of analysis. Initial results are promising with linear calibration curves generated by the LC/QTOF high resolution mass spectrometer. Instrument blanks and laboratory blanks do not detect any PFAS compounds.

If you have any questions, please do not hesitate to contact me.

Best regards,

Ralph N. Mead, Ph.D.

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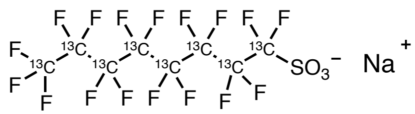
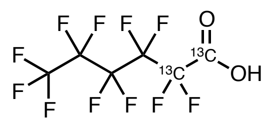
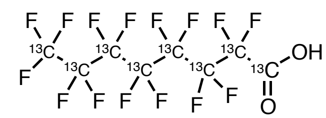


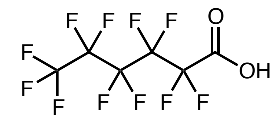
Sodium pefluoro-1-[$^{13}C_8$]octanesulfonate



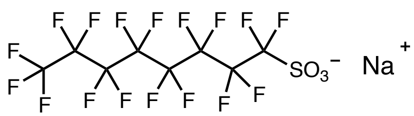
pefluoro-n-[1,2-$^{13}C_2$]hexanoic acid



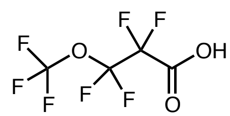
pefluoro-n-[$^{13}C_8$]octanoic acid



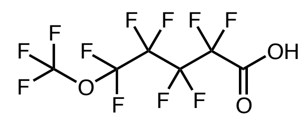
Perfluorooctanoic acid (PFOA)



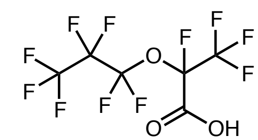
Sodium pefluorooctanesulfonate (PFOS)



Perfluro-3-methoxypropanoic acid



Perfluro(4-methoxybutanoic) acid



2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoic acid

Figure 1: Structures of perfluorinated alkyl substances purchased to date as authentic standards. The ^{13}C enriched compounds will be used as internal and surrogate standards for the analysis. As the research progresses more standards will be purchased for structural conformation as well as QA/QC purposes.

Cape Fear Public Utility Authority

Project update for the period covering October 1 – 31st, 2017

Summary:

The focus of this month's efforts has been on method validation and figures of merit as outlined in the previous month's report; we are on target with our timeline. A mixture of perfluoroctanoic acid and perflouro-2-propoxypropanoicacid were used as initial surrogates since these compounds represent the linear saturated and ether homologues respectively. Baseline separation of both compounds has been achieved using ultrahigh performance liquid chromatography/mass spectrometry. The ion trap mass spectrometer is operated in multiple reaction monitoring mode where a precursor mass is isolated and subsequently fragmented and scanned by the mass spectrometer. The ion trap mass spectrometer is considered a tandem-in-space instrument and provides a full scan spectrum of the products ions generated. This gives multiple qualifier ions that aids in confirmation of the analyte of interest in addition to retention time. This can be observed in the product scan of perflouro-2-propoxypropanoic acid (figure 2a) and perfluorooctanoic acid (figure 2b). Typical calibration curves are presented for perflouro-2-propoxypropanoic acid (figure 3a) and perfluorooctanoic acid (figure 3b). Generating calibration curves of both compounds over several days gave average slopes and standard deviations of 223±28 and 4033±656 for perflouro-2-propoxypropanoic acid and perfluorooctanoic acid respectively illustrating the precision of the measurement. The average goodness of fit (R^2) for perflouro-2-propoxypropanoic acid and perfluorooctanoic acid was 0.998 and 0.999 respectively. Spike recoveries have been assessed for perfluorooctanoic acid using Cape Fear River water as the matrix. Briefly, a known concentration of (86 ppb) was

added to unfiltered upper Cape Fear River (Horseshoe Bend) and processed for LC/MS analysis. A corresponding unspiked sample was processed as well for background concentration and subtracted from the spiked sample. Recoveries for perfluorooctanoic acid were 80 % and 108 % (n=2). This range is within the requirements for EPA Method 537 of 70-130%. The limit of detection for perflouro-2-propoxypropanoic acid is 1 pg mass on column and 27 pg mass on column for perfluorooctanoic acid.

We are in discussion with Zerenex Molecular based in the United Kingdom for custom synthesis of perfluoro-2-methoxyacetic acid (PFMOAA) for quantification and structural conformation of this compound. Several of the standards outlined in the September presentation have been ordered for structural conformation and quantification as well. Lastly, the biosolids have been all been extracted and cleaned up over anion exchange column awaiting analysis by LC/MS.

The goals of the coming month are the following:

1. Complete the percent recoveries of PFAS in river water.
2. Incorporate the isotopically labeled internal standards in the analysis.
3. Obtain a new preparative solid phase extraction phase that selectively retains the fluorinated compounds. The mechanism of retention is different than the traditional anion exchange phase commonly used. If this new phase works than it will allow us to only investigate and characterize fluorine containing organic compounds. See this link for an example: http://fluorous.com/fspe.php
4. Complete analyses of biosolid samples.

Figure 1: Extracted ion chromatograms of perflouro-2-propoxypropanoic acid (a) and perflourooctanoic acid (b) analyzed by ultra high performance liquid chromatography/mass spectrometry. The ion trap mass spectrometer was operated in multiple reaction monitoring mode.

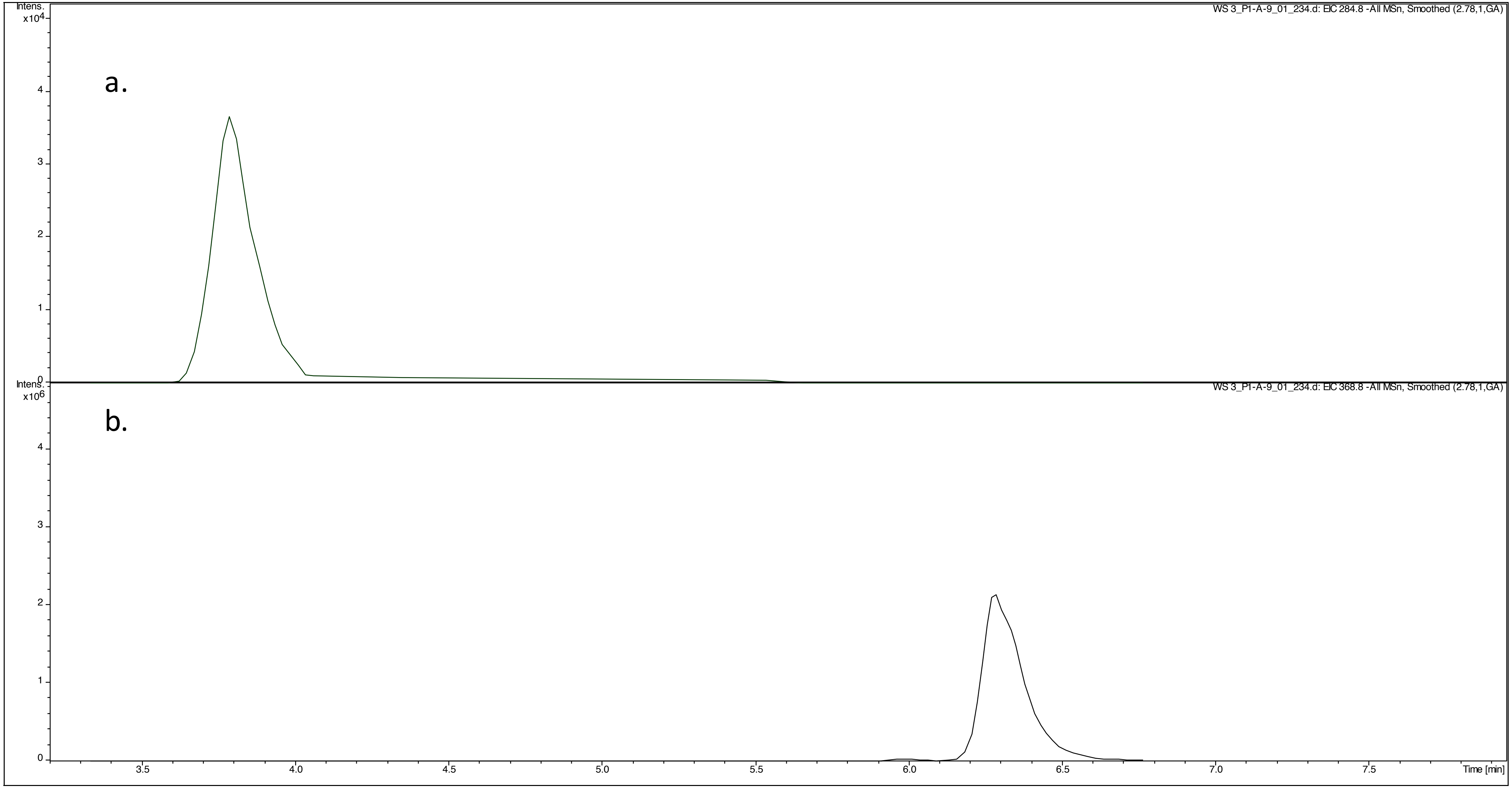


Figure 2: Product scans of perflouro-2-propoxypropanoic acid (a) and perflourooctanoic acid (b) analyzed by ultra high performance liquid chromatography/mass spectrometry. The ion trap mass spectrometer was operated in multiple reaction monitoring mode.

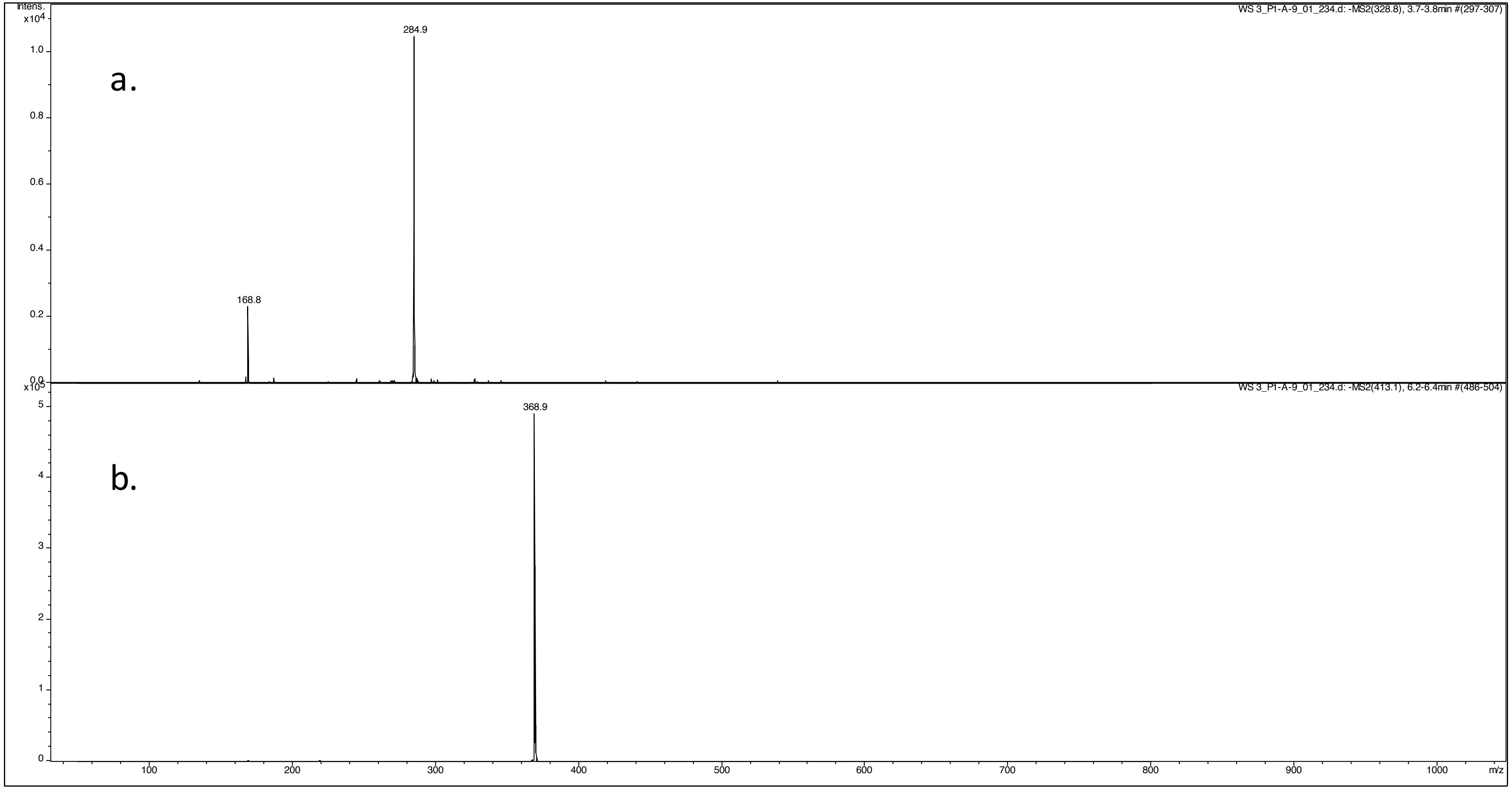


Figure 3: Typical calibration curves of perflouro-2-propoxypropanoic acid (a) and perflourooctanoic acid (b) analyzed by ultra high performance liquid chromatography/mass spectrometry. The average slope and standard deviation of replicate calibration curves (n=3) for perflouro-2-propoxypropanoic acid is 223±28 while the perflouroocanoic acid is 4033±656.